Historical Information
H.1 General

Book 7

Project Rulison Phase II Final Report, December 28, 1972

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PNE-R-60

PROJECT RULISON

PHASE II

FINAL REPORT

DECEMBER 28, 1972

Contract No. AT(26-1)-429 between the Atomic Energy Commission, the Department of Interior, Austral Oil Company Incorporated, and CER Geonuclear Corporation.

CER Geonuclear Corporation
Las Vegas, Nevada

PREFACE

This report summarizes the preparations for and results of Project Rulison with the exception of the reentry program. Much of this information has been abstracted from detailed reports issued by the participants. These reports can be found in the open file or open literature. Abstracts and descriptions of these reports are located in Appendix A of this report.

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1. INTRODUCTION

Project Rulison was a joint experiment sponsored by Austral Oil Company Incorporated, of Houston, Texas, the U.S. Atomic Energy Commission and the Department of the Interior, with the Program Management provided by CER Geonuclear Corporation of Las Vegas, Nevada, under contract to Austral. Its purpose was to study the economic and technical feasibility of using underground nuclear explosions to stimulate production of natural gas from the low productivity, gas bearing Mesaverde formation in the Rulison Field.

The nuclear explosive for Project Rulison was detonated at 3:00 p.m. plus 0.1 second Mountain Daylight Time, September 10, 1969, at a depth of 8,425.5 feet below ground level and was completely contained. Preliminary results indicated that the Rulison device behaved about as expected; i.e., with a yield of $40 \pm {}^{20}_{4}$ kt. The wellhead of the emplacement well, Hayward 25-95A, is at an elevation of 8,154 feet above mean sea level (MSL) and is located 1,976.31 ft east of west line and 1,813.19 ft north of south line of Section 25, Township 7 South, Range 95 west of 6th p.m., Garfield County, Colorado, which corresponds to geodetic coordinates of longitude 107° 56' 53" W and latitude 39° 24' 21" N. The general area and site location are shown in Figure 1, and the geodetic coordinates shown in Figure 2.

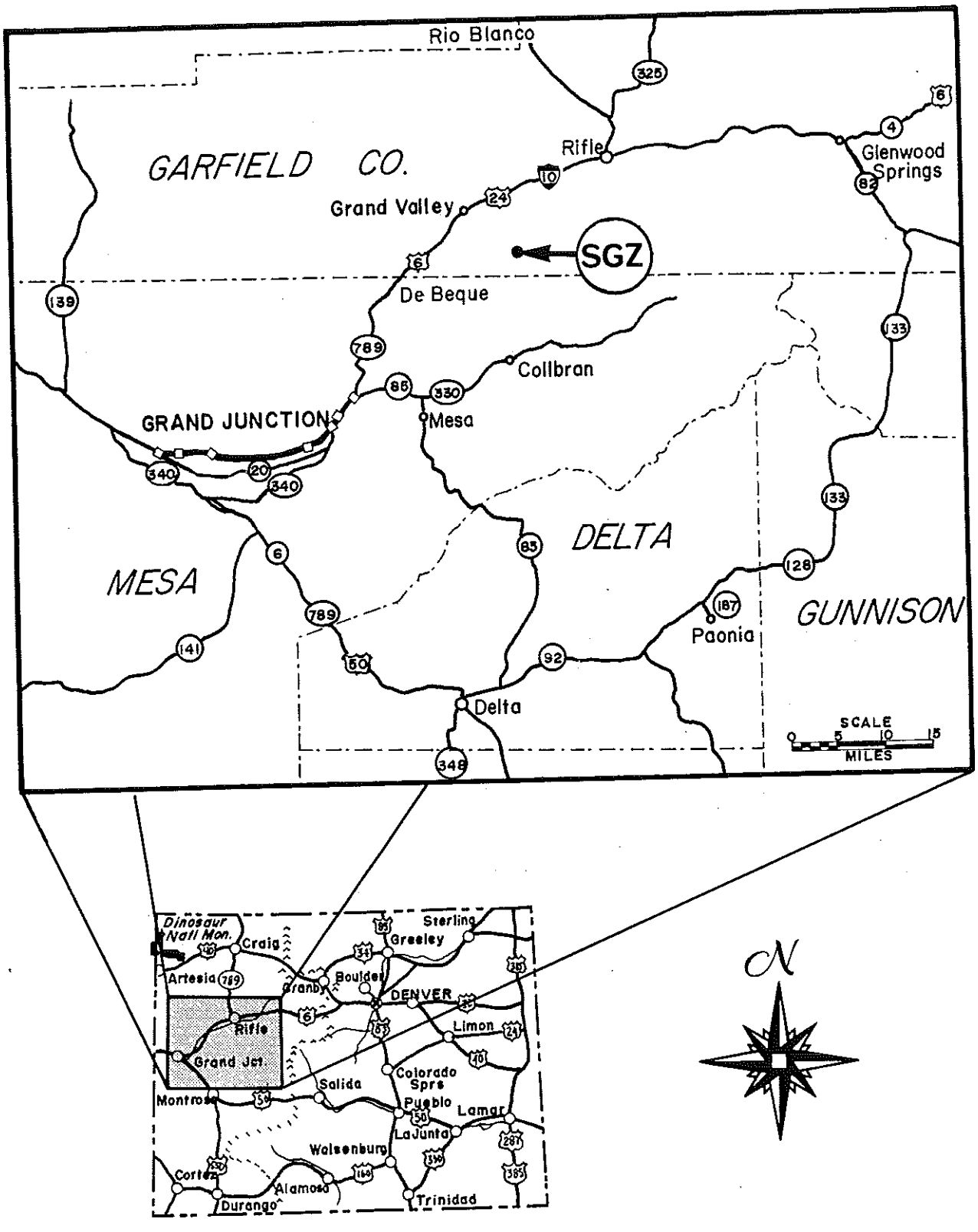

Figure 1. Project Rulison location.

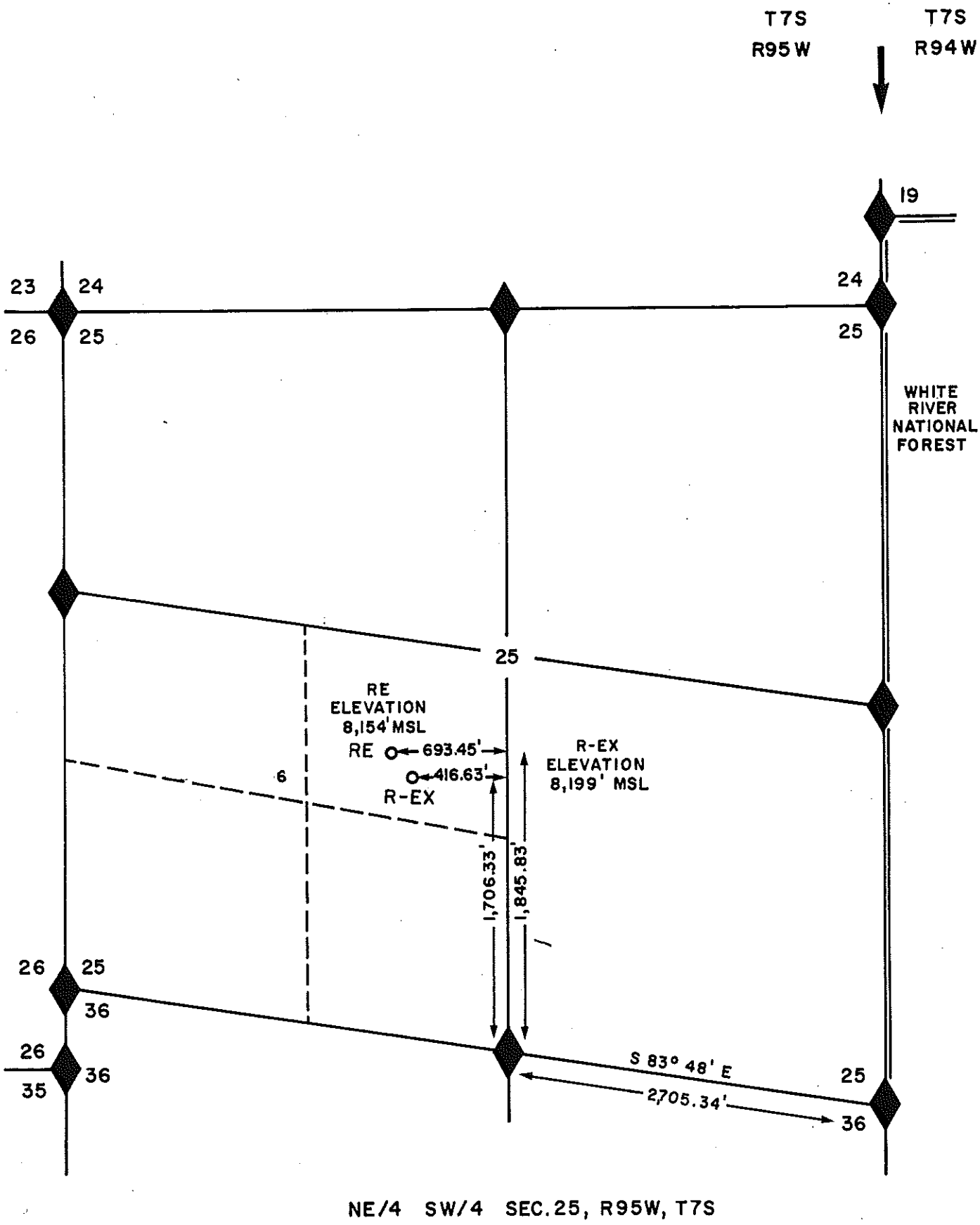

Figure 2. Project Rulison well location plat.

2. HISTORICAL BACKGROUND

Austral Oil Company Incorporated (Austral) became interested in the use of nuclear explosions to stimulate gas reservoirs early in 1965 and began to evaluate properties which might be amenable to this approach. The Mesaverde Formation in the Rulison Field of west central Colorado appeared to be suitable.

Austral initially acquired approximately 20,000 acres from other operators and options on an additional 20,000 acres. At Austral's request, CER Geonuclear Corporation (CER) conducted a surface site tour in the early winter of 1965/1966 which further indicated that the site had the potential for nuclear stimulation and that such stimulation could be done safely.

Work immediately started on the preparation of a detailed nuclear stimulation feasibility study, additional leases were obtained, and two test wells drilled. Upon completion of these wells in the spring of 1966, Austral/CER carried out an extensive well testing program to verify earlier calculations of gas in place and more accurately define the producing characteristics of the Mesaverde reservoir.

In July of 1966, Austral/CER submitted a formal letter of intent to the Atomic Energy Commission (AEC) along with the detailed report "The Project Rulison Feasibility Study."

Austral met with the United States Geological Survey (USGS) in September 1966 to discuss a unit agreement for the Rulison Field which would provide for development of the field through the use of nuclear stimulation.

In December 1966, Austral and CER made a formal presentation of Project Rulison to the AEC and on February 17, 1967, Austral reiterated its complete commitment to this project to the Joint Committee on Atomic Energy.

During the spring and summer of 1967, Austral, CER, and Lawrence Radiation Laboratory (LRL) personnel discussed the criteria for the actual site selection, inspected the proposed site area, and evolved preliminary drilling specifications for the project's exploratory well, R-EX (Hayward 25-95). The Joint Committee on Atomic Energy, in their AEC authorizations, recommended that either Rulison or Dragon Trail (another gas stimulation experiment) be accomplished in fiscal year 1968.

On October 4, 1967, Austral and the USGS signed a unique nuclear stimulation unit agreement which recognized the experimental nature of the project and the time frames necessary to complete the experiment. The unit, as approved, encompasses 50,821.41 acres.

In late summer of 1967, Austral built a 3-1/4-mile road from Morrisania Mesa to the project site. The contract for drilling R-EX was signed on November 1, 1967, drilling operations started on November 9, 1967, and the well was completed on May 6, 1968.

The development of a technical plan was aided by discussions at a number of meetings between Austral, CER, LRL, and U.S. Bureau of Mines (BuMines) personnel. In April 1968, the supporting laboratory assigned to Project Rulison was changed from LRL to Los Alamos Scientific Laboratory (LASL) by direction of the AEC Division of Peaceful Nuclear Explosives (DPNE).

The concept for the development of the Rulison project definition phase was first presented on May 7, 1968, at a meeting between the AEC Nevada Operations Office (NVOO) and CER. This concept was that a Project Definition document, prepared by industry with help and guidance from NVOO, BuMines, and LASL, was to contain the experimental, executional, operational, and managerial plans necessary to fully define the scope of the project and was to serve as the basis for the industry and government contract negotiations.

On May 10, 1968, Austral and CER representatives met with representatives of NVOO, LASL, Air Resources Laboratory, a Division of Environmental Science Services Administration (ESSA) in Las Vegas (ARL/LV), United States Public Health Service (USPHS), and BuMines and agreed upon the overall plans for the development of this Project Definition document.

A second meeting was held in Grand Junction, Colorado, on June 11 and 12 to further the project definition. On July 2, 1968, a proposed Project Definition outline and schedule were presented to NVOO.

Drilling of the Rulison emplacement well started in September, 1968, and CER submitted a draft copy of the Rulison Safety Plan to NVOO for comment.

In January 1969, CER executed a letter contract with NVOO for ground motion predictions, structural response, population, and ecological surveys to be performed by USPHS, John A. Blume and Associates (JAB), Battelle Memorial Institute (BMI), and Environmental Research Corporation (ERC). Also in January, the Project Definition report was completed and contract negotiations were begun between Austral, CER, and AEC.

The Rulison emplacement well was completed on January 30, 1969. In March a letter agreement was executed with NVOO concerning additional safety investigations to be made by USPHS, Eberline Instrument Corporation (EIC), Isotopes, Inc., ARL, Coast and Geodetic Survey (C&GS), USGS, BuMines, and JAB with work to be completed by April 15. On March 20, the construction contractors began on-site work.

The contract between the Government, Austral, and CER was signed on March 26, 1969, and on April 11, 1969, the Safety Panel convened at NVOO and recommended that additional information be developed on the Harvey Gap Dam and Battlement Mesa reservoirs. This latter request was the result of some of the first preliminary safety reviews in February where concern was expressed as to the possible effect that the seismic shock would have on the Battlement Mesa reservoirs and the Harvey Gap Dam. This concern was expressed principally because JAB had not yet completed a field survey of these areas. Later in the spring, field surveys were completed.

On May 1, the reservoir field survey data of Battlement Mesa were presented to the Safety Panel. The following are comments submitted to R. E. Miller, Manager of the Nevada Operations Office by the Safety Panel:

> "The Panel considered the possibility of failure of several or all of the small dams on Battlement Mesa. Even in the unlikely event that all reservoirs failed more or less simultaneously, with normal AEC precautionary measures, there would be no hazard to life and potential property damage would be within acceptable limits."

Particular emphasis was placed on the Harvey Gap Dam at this May 1 meeting. JAB's main conclusion was:

> ". . . while it is extremely unlikely that the dam will be damaged by the Rulison Shot, it is prudent to take certain minimum precautions which include lowering the reservoir level."

Thus, on May 7, NVOO announced a postponement and the Rulison site was "mothballed."

On May 28, NVOO issued their Project Rulison Planning Directive and on July 16, the new readiness day of September 4 was announced. Contractor activities for site preparation recommenced on July 21 with scientific occupancy starting on August 4.

The nuclear explosive was lowered into position on August 15 and the stemming operation started.

On Friday, August 22, 1969, the Colorado Chapter of the American Civil Liberties Union brought suit on behalf of three individuals in the Federal District Court for the District of Colorado against Dr. Glenn T. Seaborg, Chairman of the AEC, Austral, and CER.

The complaint asked that the defendants be permanently enjoined from exploding the nuclear device or that, as an alternative, the defendants be temporarily enjoined from the detonation pending an administrative hearing for the plaintiffs before the AEC. The motion for preliminary injunction was set for hearing on August 26, 1969, in the Court of Chief Judge Alfred Arraj.

On August 25, a second action seeking to enjoin the Rulison detonation was filed in the same Court against Austral and CER by the Colorado Open Space Coordinating Council, Inc.

The two preliminary injunction requests were consolidated for hearing on August 26-27.

The plaintiff's request for preliminary injunctive relief was denied. However, the Court did direct that the anticipated chimney reentry not be started earlier than 6 months after the detonation unless the defendants came into Court before that time and the plaintiffs were given the opportunity to be heard.

Appeal to the two cases were taken to the Court of Appeals for the Tenth Circuit on August 28, 1969, and motions for injunctive relief were argued before the three-judge Court and briefs were filed on August 29, 1969. On September 2, 1969, the Tenth Circuit affirmed the lower Court's denial of preliminary injunctive relief. A further appeal was taken to the United States Supreme Court, and on September 3, 1969, Justice Thurgood Marshall denied the motion of the plaintiffs for a stay order addressed to the Judgment of the Court of Appeals for the Tenth Circuit.

While the first two cases were being argued before the Court of Appeals, a third suit seeking injunctive relief was filed on August 29, 1969, in a Colorado State District Court. The suit named as defendants Austral, CER, and the owner of the land on which the detonation was being conducted and sought to enjoin participation by the defendants in Project Rulison. Defendants immediately removed the action to the Federal District Court in Denver, which Court (per Chief Judge Arraj) determined that there was a Federal question and that the land owner had been made a party fraudulently and in bad faith to preclude the Federal Court from having jurisdiction. The plaintiff then requested an immediate hearing on his motions for injunctive relief, and these matters were heard on September 3, 1969. The Court stated that it was consolidating the three cases for purposes of trial on the merits. Following a hearing, plaintiff's request for preliminary injunctive relief was denied.

That afternoon, the plaintiff docketed an appeal with the Court of Appeals for the Tenth Circuit. Briefs were filed the next morning and later in the day the Court of Appeals, per order of Judge Breitenstein, denied the request for immediate injunctive relief.

After the detonation of the Rulison device, plaintiffs amended their complaints to permanently enjoin the reentry of the nuclear-formed chimney and the subsequent well testing and flaring. Defendants withdrew their motions for summary judgment and to dismiss, and, after a short period of discovery, the cases were set for trial for the week beginning January 12, 1970.

September 4, 1969, was to have been detonation day; however, due to the maximum credible accident model selected for Rulison, several days of delay were ordered by NVOO's Director of Nuclear Operations (DONO), Robert H. Thalgott. These delays were due to winds in the detonation area being incompatible with the acceptable patterns of the "venting model." Therefore, Project Rulison was detonated on September 10, 1969.

3. PROJECT OBJECTIVES

The principal objective of the Project Rulison Technical Program was to determine the economic feasibility of nuclear stimulation for the commercial development of the Rulison Field. The Rulison area, with its moderately deep, thick, lenticular, low permeability sequences of the Mesaverde, Wasatch, Fort Union, Lewis, and Erickson formations, is typical of many gas fields, and the information obtained would have an important bearing on the commercial possibilities of nuclear stimulation of other areas.

A. PRODUCTION INFORMATION

The following areas of production information were of primary concern:

1. The pre- and postdetonation net production interval in the nuclear-stimulated portion of the reservoir.

2. The important postdetonation gas reservoir characteristics such as effective height and volume of the chimney and the effective fracture zone radius as determined by production testing.

3. The pre- and postdetonation flow capacity.

4. The changes (if any) of the effective flow capacity of the nuclear-fracture zone with time and decreasing reservoir pressure.

B. ECONOMIC INFORMATION

It was hoped that the costs incurred in the operational aspects of the experiment, such as construction, fielding, and support, together with the technical data, would allow some assessment of the costs related to future commercial development of the Rulison Field. This was not the case, however, since the legal activities distorted costs associated with the experiment. Costs of the Rulison Project, up through Phase II, are listed in Section 10.

C. PRODUCT RADIOACTIVITY

Information was sought as to the degree and species of radioactive contamination present in the gas from the nuclear chimney at drillback and the amount of residual activity in the produced gas as a function of time, rate, and cumulative production.

D. YIELD ESCALATION AND DATA EVALUATION PROGRAM

The purposes of the yield escalation and data evaluation program were:

1. To determine the ground motion as a function of slant range from the point of detonation.

2. To assess the degree of amplification caused by the acoustic impedance mismatch between an overlying alluvial layer and the underlying rock layers.

3. To assess, if possible, the effect of the geological formations on the seismic signals.

4. To determine the seismic effects on cultural features.

5. To obtain signal peak amplitudes, durations, and frequencies as a function of slant range from the point of detonation.

From this information and analysis, a scaling technique applicable to the Project Rulison area for a $40 \pm \frac{20}{4}$ kt yield was derived. With this technique, the structural response investigations, and appropriate assumptions based on all available data, the explosive yield for optimum nuclear stimulation of any additional wells throughout the unit can be made.

4. SAFETY AND DOCUMENTATION PROGRAM

The Safety Program for Project Rulison was concerned principally with possible accidental release of radiation to the atmosphere and ground motion effects.

The documentation consisted of the following areas:

1. Public health and safety, including evaluation of any possible effects on the surrounding ecological system.

2. Meteorological support to the radiological safety effort.

3. Peak ground motion and structural response predictions, the measures required to document the ground motion, and the response of structures to the ground motion.

4. Evaluation of the need to evacuate occupants of seismically susceptible structures.

5. Measures to evaluate the safety of mines, wells, and pipelines.

6. Study of geologic, geophysical, and hydrologic considerations related to potable water sources and their protection from contamination by radioactive materials.

The safety organizations and their areas of responsibility were:

1. Battelle Memorial Institute: Investigated possible effects of Rulison on the ecology of the area.

2. Eberline Instrument Corporation: Was responsible for on-site radiological safety.

3. Environmental Research Corporation: Predicted ground motions and the possible resultant damage to below surface (mines, wells, etc.).

4. ESSA-ARL: Supplied meteorological support to the safety program.

5. Isotopes Incorporated: Was responsible for calculating movement of radioactivity in relation to ground water.

6. John A. Blume and Associates: Evaluated the potential effect of ground motion on all surface structures in the area.

7. U.S. Coast and Geodetic Survey: Was responsible for installing, maintaining, and operating the ground motion measuring equipment.

8. U.S. Geological Survey: Was responsible for hydrologic studies.

9. U.S. Public Health Service: Performed the radiological health and safety services required for any AEC test site.

10. U.S. Bureau of Mines: Surveyed mines and gas wells to identify, evaluate, and minimize potential hazards.

A. ON-SITE RADIOLOGICAL SAFETY

On-site radiological safety was required to safeguard project personnel and neighboring population during and after the detonation and to document any effluent release.

B. SITE CHARACTERISTICS

The effort to obtain off-site safety resulted in the execution of detailed surveys and plans based upon investigations of the surrounding area.

1. Population Survey

A detailed survey was made documenting the number of people, residences, and milk cows out to a radius of about 25 miles from Surface Ground Zero (SGZ). The survey was supplemented in other parts of the safety program (ground motion and structural response) by the identification of surface and underground structures that needed to be evacuated at detonation time to avoid a ground motion hazard to the occupants.

2. Medical and Veterinarian Support

Arrangements were made to provide medical support for the evacuation of any invalids living in the project area and prompt medical and veterinarian services in the event of project-related injury to members of the public or to livestock.

3. Seismic Program Support

An evacuation plan was prepared and provisions made for compensating families for their inconvenience. In addition, a public relations program was developed to inform the populace of the general nature of the ground motion and the measures being taken to avoid injury.

4. Dosimetry

An array of thermoluminescent dosimeters (TLD) was established at readily accessible locations as close as possible to the circumference of a 5-mile radius circle around SGZ.

5. Air Samplers

Air samplers were placed at each population center within 10 miles of SGZ and at a few appropriate locations beyond 10 miles.

6. Milk and Vegetation Sampling

A milk and vegetation sampling program was devised based upon the milk cow population survey. Background samples were collected prior to the detonation and assayed for radioactivity. Milk and vegetation samples were collected after the event, if necessary.

7. Field Evacuation and Radiation Monitoring

Radiation monitors and equipment were fielded according to the area control plan.

8. Aerial Radioactivity Monitoring Sampling

Aircraft assigned to radioactivity monitoring and sampling missions were orbiting upwind from SGZ at detonation time and other surveillance aircraft were on "ramp standby" status.

9. Ground and Surface Water Sampling

All ground sources of water in the Battlement Creek drainage and all surface sources within 5 miles of SGZ were located and the quality documented. A water sampling station was established at each source, including one in Battlement Creek Valley located about 2 miles downstream from SGZ and about 1-1/2 miles upstream of the nearest habitation. At this location, before the event, a water well was drilled through the alluvium to bedrock.

Water samples were taken before and after the detonation to determine background activity and to document any change of activity. Periodically, postdetonation samples were collected from the close-in ground water station and any springs above this station.

10. Prediction of Ecological Effects

An evaluation of the ecological system in the Rulison event area was made to predict possible effects of the detonation and to recommend preventive or remedial courses of action.

C. METEOROLOGICAL SUPPORT FOR RADIOLOGICAL SAFETY

Prior to the operational phase, climatological studies were made of the winds in the Rulison event area based upon records from the weather archives and other sources. In addition, mechanical weather stations were established and operated at four locations in the Battlement Creek drainage.

During the operational phase, supplemental equipment was installed at three locations to provide additional data on winds aloft.

As the scheduled time of detonation approached, the project forecaster and radiation briefer used the available data to prepare periodic forecasts. Based upon the postulated maximum credible release model, their predictions included a possible trajectory fallout sector and predicted dose rate.

D. GROUND MOTION AND STRUCTURAL RESPONSE

A ground motion and structural response program was required on the Rulison project to satisfy not only the safety requirement but also the technical objective of evaluating the maximum explosive yield that could be used if the Rulison Field were to be developed commercially with nuclear explosives.

Ground surface features such as canyon walls, slopes, dams, embankments, and soils supporting bridge abutments that might cause property damage or be personnel hazards under the influence of ground motion were identified.

The structural response program evaluated the response of structures in the area as part of the technical and safety objectives, evaluated the possible increase in the yield of possible follow-on nuclear explosions in the area, and provided a basis for evaluating damage complaints.

The preliminary predetonation survey gathered information on the nature, age, condition, and the value of structures; the character of foundation material; and local construction costs and building practices. A preliminary estimate was made of special hazards, probable damage, and repair costs.

Selection was then made of close-in structures for pre-event detailed investigation and documentation. Data was obtained on the approximate dimensions of each structure, the type and materials of construction and foundation, age, general condition, location, and approximate value. Photographs were taken of existing defects and portions of the structure apparently subject to incipient failure. On the basis of the information gathered in the detailed investigation, an analysis was made of the anticipated structural response and damage predictions developed. In

addition, recommendations were made for development of seismic instrumentation and for measures required to minimize structural damage and to avoid personal injury. The results and recommendations were summarized in the predetonation report.

A few days prior to the event, the structures were checked for any change in condition. At the time of the detonation, observers were stationed in selected areas to monitor the response of certain structures to the ground motion, to provide reports of perceptibility, and to document any damage in the area attributed to the ground motion.

A post-explosion resurvey was made of the documented structures. This resurvey was expanded as required to provide engineering support in determining the validity of damage complaints. Evaluations of damage occurring from the event and assessments of public reaction and damage complaints were made.

The safety of mines, wells, and pipelines involved a predetonation field survey of the area to investigate the mines and wells and associated pipelines, to evaluate their condition, and to identify the scope of requirements.

The predetonation mine survey included visual inspection and photographs of potential areas of damage within the mine and the installation of such instrumentation as necessary to document seismic response.

E. GEOLOGIC, GEOPHYSICAL, AND HYDROLOGIC PROGRAMS

Programs in geology, geophysics, and hydrology were undertaken to provide data necessary to evaluate the safety of the Rulison event.

Data developed from the R-EX and RE wells and coordinated with other geophysical and hydrologic data were used to develop a large scale geologic cross section containing the point of detonation. The geologic map and cross section was provided to each project participant concerned with evaluating containment, groundwater contamination, and predicting the amplitude of ground motion.

F. CONTAINMENT ANALYSIS

Since the depth of burial of the Rulison device exceeded the accepted containment criteria by at least a factor of 4.7, the question of containment was reduced to the determination of the absence of significant faulting in the event area and the evaluation of the plans for casing, cementing, and stemming. Surface study of the Rulison site area by the USGS and by geologists of Austral, CER, and LRL developed no evidence of surface faults within a few miles of SGZ. The stemming plan proposed by LASL was evaluated and approved by the AEC's Test Evaluation Panel as was the casing and cementing plan.

5. EXPLOSIVE OPERATIONS

A. EMPLACEMENT

The nuclear explosive was lowered on double-armored wire rope with a multi-conductor cable core. To lower the rope, Austral provided a skid-mounted, power-operated winch. A sensitive weight indicator was the winch operator's primary indication that all was well during the lowering of the nuclear explosive. Minimum rope speed for lowering the explosives with power control was 1 foot per second. The winch also employed deadman controls as an additional safety precaution. Approximately 16 hours was required to emplace the nuclear explosive.

B. STEMMING

1. Material

The stemming material, consisting of sand and gravel, developed into an expensive proposition. Because of insufficient time to analyze locally available material for suitability, sand and gravel at the Nevada Test Site was processed, sacked, palletized, and trucked to Las Vegas where it was loaded into five railroad freight cars and shipped to Grand Valley, Colorado. There is was unloaded and trucked to the Control Point area for storage. During the delay period the palletized sacks of sand and gravel were covered with large sheets of polyethelene to maintain the specified dryness tolerance.

2. Exploratory Well

A problem developed during the stemming of the exploratory well when bridging occurred. Attempts to break the bridged section were unsuccessful. Remedial efforts required mobilization of a drilling rig to clean out and cement the inside of the casing.

3. Emplacement Well

Stemming of the emplacement well was performed as described in the Project Definition Plan. The rate of feed of the stemming material was controlled by the opening of the gate on the bottom of a hopper. The hopper fed the material to an electric conveyor belt which carried the material into the emplacement well. Due to the slow rate of feeding the stemming material into the well, approximately 14 days around the clock was used for the stemming operation.

C. FIRING SYSTEM

The firing system furnished by LASL was set up as described in the Project Definition Plan. The system was relatively simple and was contained within one 8- x 45-foot trailer. After the CER subcontractor installed the signal and coaxial cable, completed the intermediate splices, and tested the cable, LASL personnel terminated the remaining two ends, one to the firing equipment and one to the nuclear explosive. No problems occurred with the firing system during the detonation of the nuclear explosive.

6. SUPPORT PROGRAM

A. EMPLACEMENT WELL AND CONTROL POINT

The primary work associated with drilling and evaluation of the exploratory and subsequent emplacement well was completed by Austral by February 1969. This work also included construction of the access road, selection of and construction at the drilling locations, and installation of a one-party business telephone line which terminated in the Austral office trailer located at surface ground zero (SGZ).

Starting in late February CER, through its subcontractors, performed event-related items such as:

1. Cleared and stabilized area for Control Point.
2. Stabilized Emplacement Well area for operational period.
3. Constructed power line to Control Point and Emplacement Well area and installed substations at each location.
4. Installed electrical distribution panels at substations and laid power cables to event-related items.
5. Installed, cribbed, shockmounted, and anchored rented and government-furnished office trailers.
6. Installed office furniture and equipment in trailers.
7. Constructed concrete foundation for Emplacement Well winch.
8. Constructed concrete cellar at wellhead.
9. Constructed security fencing around wellhead shack.
10. Constructed security lighting around wellhead shack.
11. Installed signal and coaxial cables from Emplacement Well to Control Point.
12. Installed splice panels and terminated cables.
13. Installed winch for emplacement of explosive.
14. Mobilized well pulling unit to serve as headframe during emplacement.
15. Pull-tested headframe and associated emplacement hardware.

16. Facilities (trailer, ambulance, and personnel) for first aid service initiated.

17. Forty-ton mobile crane on standby at Emplacement Well for unloading nuclear explosive.

18. Stemming sand and gravel delivered to the Control Point area for storage.

19. Installed security standby generator.

20. The following facilities were located at the Emplacement Well and readied for delivery of the nuclear explosive:

    a. Ambulance
    b. First aid
    c. J-1 Office
    d. J-6 Office
    e. Security
    f. Emplacement headframe and hardware

21. The following facilities were located at the Control Point and readied for delivery of the nuclear explosive:

    a. ARL Office
    b. AEC-OCC-AOC Office
    c. Program Manager Office
    d. Technical Director Office
    e. LASL Administrative Office
    f. Arming and Firing Trailer
    g. Security Office
    h. Radiological Safety Office and Laboratory

22. Normal support services initiated.

Due to the impending delay, little additional preparatory work was performed after May 1 and the balance of the government-furnished equipment was not delivered to the site. Most of the month of May was spent mothballing, returning vehicles and equipment, packing and shipping project participant's belongings to their home stations, and placing the project on standby for a September experiment date.

During the standby period, industrial watchmen service was provided around the clock, 7 days a week to protect the equipment remaining at the project.

On July 28 the construction activities resumed, primarily directed at reactivation of the facilities for a September 4 detonation date. The well pulling unit (which was to be used as the emplacement headframe) had not been removed from the Emplacement Well area and it was determined by LASL that an additional pull test of the emplacement headframe and hardware was necessary. The ARL and Security trailers were installed, cribbed, shockmounted, and anchored. The Security van was reinstalled in the Emplacement Well area.

Delivery of the nuclear explosive package was as scheduled although difficulty was experienced with a steep grade on the access road where the vans had to be towed. Unloading and movement to the wellhead shack was without incident. After LASL completed its check on the nuclear explosive package the device was emplaced. As soon as the well pulling unit was removed and permission was granted, the stemming material was transported from the Control Point area to the Emplacement Well and the stemming was started. A great deal of time was required to stem the Emplacement Well and it is hoped that a better method will be found in the future. As stemming of the well progressed, unused facilities such as trailers, winch, chemical toilets, etc. were relocated to the Control Point or observation area.

B. PREDETONATION REPAIR

1. Chimneys

Nine chimneys were repaired prior to the detonation by one of the following methods:

a. Removing the chimney to roof line and rebuilding with new bricks and mortar.

b. Removing the chimney to roof line and replacing with metal flue.

c. Boxing existing chimney (in place) with plywood and lumber and bracing or guying to ground.

No damage claims were received on these chimneys after the experiment.

2. Mobile Homes

Support mechanisms for two trailers were rehabilitated prior to the detonation. Existing blocking was removed and the trailer leveled that and new cribs of 8-in. x 8-in. x 8-ft timbers laid log cabin style at the ends and center of trailer. Postdetonation inspection revealed that no visible horizontal movement occurred. No damage claims were received on this preventive work.

3. Miscellaneous

Repairs were made to the cellar of one house. The old brick and rock walls of the cellar were in poor condition including one wall that had caved in. Also the supporting earth pedestal of a fireplace's rock foundation was exposed.

Repair work consisted of cleaning out the collapsed brick and rock and excavation of the caved in wall to obtain a level cellar floor. All walls and the earth pedestal of the fireplace were then gunited utilizing mesh reinforcement. Supports to the exterior floor frame of the house were repaired or replaced. As a result of this repair work, no damage claim was submitted postdetonation on these items.

C. COMMUNICATIONS

One hardwire telephone line installed by Mountain Bell Telephone Co. was shared between the Project Rulison Emplacement Well and Control Point area and terminated in the Grand Valley exchange. The estimated cost to have Mountain Bell Telephone Co. install additional service was $34,000 since it involved extension of their cable system. An attempt was made to provide additional telephone capability from the Public Information Trailer in Grand Valley to the AEC and Laboratory Trailer at the Control Point via radio link and accoustic coupling to Mountain Bell Telephone Co. circuits. This equipment (4 telephones in rotary configuration and 4 acoustic couplers to the radio links) was installed and operational approximately 2 weeks prior to the announced delay in early May. When project participants returned in August no attempt was made to reinstall this system since they felt that it was inadequate.

Other telephone lines installed by Mountain Bell Telephone Co. at CER's request prior to the announced delay and subsequently cancelled or radically modified were as follows:

1. Rifle office, modified.

2. Public Information Office, cancelled.

3. Air Operations Office at Walker Field, cancelled.

4. ARL telephone, TWX and FAX at Walker Field, cancelled.

5. Additional acoustic coupled telephone service to Control Point (CP), cancelled.

6. Western Environmental Research Laboratory at Grand Junction, cancelled.

7. USPHS, Grand Junction, cancelled.

At the onset of the second operational period, the above telephone lines were again installed.

In addition, the AEC required and supplied a four-channel microwave system to provide additional communications to the Control Point. One terminal of the microwave system was located at Anvil Point where adequate telephone service could be supplied by Mountain Bell Telephone Co. The other terminal of the microwave system was located approximately 1/2 mile northwest of the Control Point. Approximately 1,200 feet of power line was constructed to provide electric service to this terminal and approximately 1/2 mile of signal cable was laid to connect the Control Point area to this terminal.

One duplex radio net was installed with the repeater located at Lands End (elevation 10,040 feet) on Grand Mesa in facilities owned by the Mesa County Road Department. Communications coverage from this location was excellent,

Very little trouble occurred with the repeater from normal use; however, on the day of the event the repeater failed due to the continuous operation mode of greater than an hour. A technician on standby restored its operational capability within a few minutes.

Two additional repeaters for extended range coverage were on standby on the day of the experiment. One was located on top of Monument Peak for additional coverage to the north. The second was located on top of Sunrise Peak for additional coverage to the east. Neither of these two standby repeaters were required on the day of the experiment.

Mobile radios supplied by the AEC performed satisfactorily. The originally scheduled 55 duplex mobile radio units supplied from the Nevada Test Site were supplemented during the delay period by approximately 30 additional units; the additional units being air freighted from Hattiesburg, Mississippi.

The CER communication subcontractor provided complete service to the government-furnished duplex radio equipment. This service included receiving, shipping, warehousing, installation, removal, maintenance, and repair of the equipment.

D. OBSERVATION SITE

Prior to the original scheduled date of May 20, the area for the observation site was cleared and stabilized. When activities began again at the site in August, the following requirements were determined:

1. Tent.
2. Display boards.
3. Speakers platform and podium.
4. Lavatory facilities (chemical toilets with sight shield).
5. Trailer for industry officials.
6. Catering service.
7. Communications link to CP to provide countdown to observers and commercial radio pickup.

In addition to providing space for the observers, this area was also developed for the use of the helicopters and associated pilots, ground crews, fuel trucks, and facilities.

It was difficult to provide electric service to all the facilities because of numerous additions which required modification of the electric supply system.

E. PUBLIC INFORMATION OFFICE

An office trailer was installed in Grand Valley for the Public Information Office (PIO) in early April 1969. After a short occupancy by the PIO personnel, the delay was announced which resulted in placing the trailer on standby status, returning furnishings, and terminating telephone service.

The office trailer was adequate for the PIO until after the court trial. After the trial, additional PIO personnel arrived and the lack of adequate space and sanitary facilities became a problem.

F. CLAIMS OFFICE

Very little project support was required since most of the support was arranged for by the General Adjustment Bureau (GAB). Because advantage was taken of available equipment such as radios and office furniture as other project participants left the area, many of the claims office requirements were not satisfied until 1 week after the detonation.

G. CLOSED CIRCUIT TELEVISION

Criteria for closed circuit television (CCTV) coverage of the Emplacement Well area during detonation were not received prior to May 1969 and, therefore, no provisions were made for CCTV cabling when the signal cables were installed. This requirement was received during the delay period and additional support items such as standby generators, commercial power, and cabling were necessary.

7. SPECIAL PROBLEMS

A. MUD PITS

When the emplacement well was completed in January 1969, the remaining drilling mud was transferred to the main storage pit. During the spring runoff, the mud was diluted with fresh water from both the melt and a suspected spring in the bottom of the pit.

In late August, the AEC decided that the seismic effect of the detonation might cause a crack to develop in the compacted earth retaining wall resulting in the contamination of the nearby stream.

It was decided to dispose of the mud by spraying it on the principal site access roads. After many days and spending $40,000, the surface level of the drilling mud was lower than the surrounding natural ground and the emptying of the mud pit was stopped.

B. WELLHEAD

Several problems were experienced with the wellhead. Several days prior to the final assembly of the wellhead it was discovered that the diameter of the hole through the packoff unit was smaller than that of the cable seal located on the end of the firing cable. A new packoff unit was ordered. Because the packoff unit was specially made, it took some time to obtain and arrived by courier just prior to the time it was needed.

In pressure testing the wellhead, one leaky flange was corrected by installing special O-rings. Also, the main flange did not pass the 3,000-pound test; the problem was corrected by compacting a fibrous material which plugged the leak.

The cable stuffing box appeared unwieldy to LASL and an alternate plan was used which consisted of completely taking out the cable stuffing box and putting split rings in its place to serve as a stop for three Crosby cable clamps placed above them. The cap assembly was then extended so that additional cable would be available for holding during drillback.

C. CEMENT TRUCKS

A multitude of relatively small, and some large, items were reported at the last minute. These items obviously cost money and in many cases were unnecessary. For instance, it was brought up at a late predetonation meeting that; "if we go back in and find the wellhead broken off, do we have any way of correcting it?" and it was requested by the AEC that cement trucks stand by in case this occurred. The trucks had to be ordered from Vernal, Utah, and when the detonation was repeatedly cancelled the costs mounted accordingly.

8. DAMAGE CLAIMS

A Project Rulison Claims Office was established by the GAB under contract to the AEC. This office, opened September 4, 1969, in Grand Valley, Colorado, was for the purpose of investigating and documenting property damage claims resulting from the September 10, 1969, nuclear detonation. Property damage claims were to be paid by the AEC with the exception of a $10,000 fee to be paid by Austral as required by the Project Rulison Contract AT(26-1)-429.

The claims office was closed on November 14, 1969. During the time the claims office was open, 362 property damage complaints were received. Of the 255 formal claims received and filed, 232 were paid a total of $51,000.

On November 11, 1969, CER requested the AEC to arrange for the GAB to investigate claims for which Austral was responsible. This included items such as loss of profits in mines and loss of profits and expenses by game hunters and guides. Since some claims involved both the Government and Austral, GAB was to determine to what extent each was liable for the payment. This arrangement also contained an agreement whereby a pro-rata share of incurred GAB expenses would be paid by Austral as well as the total hourly charges spent in the investigation of that portion of claims in which the industrial partner was liable.

Between November 14, 1969, and August 31, 1970, the claims office was located in Grand Junction, Colorado. The Grand Valley Project Rulison claims office was reopened August 31, 1970, 11 days prior to the anniversary date of the Rulison detonation of September 10, 1969. The September 10, 1970, date was the final day for residents to file claims. During the 11 days, 35 damage complaints were received of which 33 were formalized as claims.

A total of 455 complaints was received by the U.S. Government. Of these, 323 claims were paid a total of approximately $122,000. Three claims are still pending but they are small and will change the final figure by only a few hundred dollars at most. The average settlement cost per claim for the Government was approximately $375.

As of November 6, 1970, 100 percent of the claims against Austral had been settled. Austral received 19 claims of which 13 were paid, 2 proportionally paid, and 4 denied with no further action to be taken. The payment for their claims amounted to $37,000, excluding the $10,000 fee on the initial contract.

In summary, when the six pending claims are paid by the Government, the final accumulative figure for all claims will be approximately $169,000. An additional expense which should be noted is the total cost for the General Adjustment Bureau's investigations (including engineering investigations) which began on September 4, 1969. This will amount to approximately $121,000.

Table 1 summarizes the claim costs.

Reports of damage from Project Rulison are summarized by type and number as follows:

Chimneys	104
Interior Cracked Plaster	177
Wells/Cisterns	41
Foundations	68
Exterior Walls	81
Household Items	14
Other	108
Combination	136

Table 1. Damage claims and costs.

	Austral	U.S. Govt.	Total
Number of Complaints Received	19	455	474
Number of Claims Paid	15*	323	338
Amount of Claims Paid ($000)	47	122	169
Investigation Costs ($000)			121
		Total Cost	$290,000

*Two claims paid proportionally by Austral and U.S. Government.

9. LOGISTICS

A. PERSONNEL

The number of people projected as needed on D-day in the Definition Plan and the actual number of people working on Project Rulison in Colorado on D-day is shown in Table 2.

B. VEHICLES

The number of vehicles used from March 1969 to November 1969 by government and industry participants is shown in Table 3. The table also shows the original number estimated.

Vehicles (sedans, station wagons, pickups, four wheel drive pickups and jeeps) were obtained primarily from Hertz Rent-A-Car up to the limit of vehicles they had available. At that time additional vehicles (sedans only) from Avis and National were obtained to satisfy the needs of the project.

C. OFFICE SPACE, EQUIPMENT, AND FURNITURE

The project office was established in Rifle, Colorado. Modification of an existing building provided office space in accordance with criteria received. However, the office space was seldom used because of its geographic location in relation to the project site and a shortage of suitable housing in Rifle. Additional office space was obtained in the Grand Junction area as follows:

ARL--rented office space at Walker Field
Air Operations--rented office space at Walker Field
WERL--provided office trailer in Grand Junction

Office furniture and equipment was rented in most instances except where it was obvious that the length of rental indicated direct purchase would be advantageous.

Secretarial and clerical help was obtained locally through CER subcontractors.

Table 2. Project Rulison population for D-Day.*

	Projected	Actual**
AEC	18	26
Austral Oil Company		5
BLM Firecrew		4
BMI		0
Bureau of Mines		10
USC & GS		7
CER		17
Colorado Bureau of Mines		10
Colorado Game, Fish & Parks		19
Colorado State Patrol		39
DRG & W		7
ESSA/ARL	10	13
General Adjustment Bureau (Claims)		4
Grand Valley Vol. Fire Dept.		5
JAB	12	12
LASL	22	22
Mesa County Road Dept.		13
Military Intelligence		3
NOAA	7	7
On-Site Rad Safe	7	11
Ops Coordination (EG&G)	3	4
REECO		3
USAF		19
USGS	1	4
US PHS	25	69
WSI	12	15
Industrial Subcontractors		
General Contractor		8
Electrical Contractor		10
Electric Utility Company		3
Propane Utility Company		8
First Aid and Industrial Safety		2
Communications Contractor		4
Public Information Office Support		12
Cementing and Pump Truck		4
Total		395

* Projected column summarized from Project Definition Plan.
**Some figures are estimates.

Table 3. Project Rulison vehicles estimated vs. actual.

Date	Date Weeks	Government Participants & Their Contractors		Industry Participants & Their Contractors		Total Vehicles	
		Estimated	Actual	Estimated	Actual	Estimated	Actual
03-25-69	-24		0		0		0
04-02-69	-23		1		1		2
04-09-69	-22		8		1		9
04-16-69	-21		13		3		16
04-23-69	-20	1*	27	0*	2	1*	29
04-30-69	-19		24		3		27
05-07-69	-18		27		5		32
05-14-69	-17		5		1		6
05-21-69	-16	6*	0	1*	0	7*	0
05-28-69	-15		0		0		0
06-04-69	-14		0		0		0
06-11-69	-13		0		0		0
06-18-69	-12	2*	0	2*	0	4*	0
06-25-69	-11		0		0		0
07-02-69	-10		0		0		0
07-09-69	-9	1	0	2	0	3	0
07-16-69	-8	3	0	3	0	6	0
07-23-69	-7	10	0	3	0	13	0
07-30-69	-6	9	7	3	1	12	8
08-06-69	-5	12	22	3	4	15	26
08-13-69	-4	23	45	3	4	26	49
08-20-69	-3	37	64	4	7	41	71
08-27-69	-2	42	88	4	7	46	95
09-03-69	-1	84	131	5	14	89	145
09-10-69	D-day	84	126	5	13	89	139
09-17-69	+1	74	8	4	1	78	9
09-24-69	+2	8	0	3	0	11	0
10-01-69	+3	3	0	3	0	6	0
10-08-69	+4	2	0	1	0	3	0
10-15-69	+5	1	0	1	0	2	0

*Vehicles requested on occasional use basis.

10. EXPENDITURES

A. DELAY COSTS

The rescheduling of the Rulison event from May 22 to September 4, 1969 resulted in delay costs of $270,900. These costs have been tabulated and segregated in time by three categories. These are:

1.	Rollup	May 1 to May 25, 1969
2.	Standby	May 26 to July 27, 1969
3.	Redo	July 17 to August 12, 1969

The costs presented are those which accrued from May 1, 1969, the original schedule for device arrival at the Rulison site, until August 12, 1969, the time of actual device arrival. This time period was chosen to represent the delay costs because scheduled site activities had been completed to this point and further production work was dependent on the device arrival. On May 1 rollup began in order to place the site on standby status with minimum cost. Site activity resumed in mid-July to again reach the point in the schedule representing a state of readiness for device arrival. Table 4 summarizes the delay costs.

Table 4. Summary of delay costs.

	Rollup ($000)	Standby ($000)	Redo ($000)	Total ($000)
Industrial Subcontractors	36.9	15.7	18.0	70.6
Government Subcontractors	29.0	27.9	34.5	91.4
CER Geonuclear Corporation	27.6	33.8	27.5	88.9
Austral Oil Co. Incorporated	8.0	7.5	4.5	20.0
TOTAL	101.5	84.9	84.5	270.9

B. EXECUTION COSTS

The execution costs are summarized in Table 5.

Table 5. Execution costs*

	Industry ($000)	Government Subcontractor ($000)	Combined ($000)
Project Development and Management	420	---	420
Drilling	1,843	---	1,843
Site Characteristics and Report	26	220	246
Site Preparation, Maintenance, and Unallocated Log Support	163	---	163
Explosive Services	---	34	34
Explosive Operations	230	---	230
Operational Safety	151	209	360
Seismic Documentation and Damage	27	112	139
Public Relations	112	7	119
Totals	2,972	582	3,554

*Costs paid by Government are unavailable and therefore not included.

11. OBSERVATIONS

In general, Project Rulison went quite well. Possibly as a first attempt, the Project went better than could be expected and many areas of doubt concerning technical and administrative functions and participant interactions were resolved. However, some broad questions are still in need of discussion.

A. DIVISION OF RESPONSIBILITY

The division of responsibility between participants left much to be desired, with each participant performing from a different viewpoint and with varying objectives in addition to the technical ones of the project. A communication mechanism is needed for future experiments which can effectively deal with the differences. It is clear that the various planning or contract documents cannot sufficiently bridge this gap. One such mechanism might be routine scheduled meetings between the participants but limited to those who actually have commitment authority to deal with problems which might come up.

The contract documents should establish broad areas of responsibility and a modus operandi. The Rulison contracts allowed some areas of confusion and doubt as to responsibility and authority. The written Division of Responsibility in the contract contained so much detail that it led to misunderstanding over items which were not covered or stated explicitly. Obviously, enough detail can never be generated to cover all the possible items and one way to designate the division of responsibility is with broad categorization.

The net result is that better joint plans must be developed in order to reduce the deviations to those which are clearly necessary or desirable and which can be jointly agreed upon. This, then, requires that those with operational responsibility and authority within the government and industry organizations participate early in the planning stages and become committed to the plans.

As the technology gets closer to commercial application, performance criteria should be developed by the government and a review system established to certify industry's compliance.

B. GUIDELINES

The area of government guidelines to industry needs developing. The government has not provided satisfactory guidelines enabling industry to develop a project without constant consultation with the government. Examples of areas needing guidelines are:

1. Well drilling
2. Communications
3. Containment
4. Safety standards

C. USE OF GOVERNMENT CONTRACTORS AND EQUIPMENT

The mechanism for the use of government equipment and contractors is unsatisfactory for future events. The problems inherent in developing plans which are dependent upon their use are many.

In the case of Rulison, certain types of equipment were in relatively short supply and, in fact, it appeared at times that equipment might be withdrawn for other projects.

Arrangements for the use of government subcontractors were necessitated by industry's lack of capability and sufficient information needed to adequately perform tasks or calculations. This was regrettable since those paying the bills under the arrangement had no input or influence with those who generated costs. An even more serious consequence was that free interchange of technical information in this environment was extremely difficult. The problem associated with the delay of dissemination of project information until it had been fully approved up and down the line is self-evident.

D. PUBLIC INFORMATION AND RELATIONS

Increased effort should be made to communicate on technical matters with the technical community. An informed technical community might counterbalance uninformed critics and provide greater acceptance.

Local acceptance would be improved by utilizing as many of the local people as possible in project activities and planning. Contact should be established at an early date in any area where operations are expected so as to be aware of local capabilities.

E. MANPOWER UTILIZATION

For future events, a specific effort to gain a greater understanding of the tasks is a basic "must" for the industrial participants. It appears that some activities can be combined or eliminated. Some tasks require specialized talents; however, others are not nearly so restrictive and can be utilized to provide opportunities to use local personnel. For instance, evacuation activities and portions of the initial safety study could have used trustworthy individuals hired locally.

F. OFFICE FACILITIES

It is clear that the Central Office should have been located in Grand Valley or Grand Junction. Very little usage was made of the Rifle office and much of the procured space was wasted.

G. WIND SECTORS AND WEATHER DEPENDENCE

The use of the particular "maximum credible" accident model for Rulison was unfortunate. Instead, one should impute a degree of confidence to the depth of burial and stemming and take appropriate safety measures for the balance of the risk. The repeated public assurances that nothing was going to vent was totally offset when the operation was based on the assumption of substantial venting.

H. OPERATIONAL SITE AND ROADS

Cost savings could have been made by a more suitable choice and layout of the operational site. For example, the requirement for closed circuit television could have been avoided had a direct line-of-sight been available between the CP and SGZ. Another problem was that the road leading to the site was built on such steep grades that much of the heavy equipment could not travel over it under its own power and had to have assistance. This was particularly true during winter operations when a large part of the work day would be lost as both equipment and personnel tried to get to their work locations. However, this was not completely unavoidable or unexpected as it was partly a result of the necessary remoteness of the site.

I. ROADBLOCKS

Roadblocks are a problem because, while possible rockfall danger exists, unnecessary inconvenience to travelers is to be avoided. During the Rulison event, there was unnecessary inconvenience to travelers on the main traffic system as well as to the local inhabitants.

For the Rulison event, about 42 roadblocks were implemented with several additional on standby, to be activated on command by DONO. Thirty-six roadblocks were activated at H-1-1/2 hr, H-1 hr, and a few at H-45 min. The duration of closure time depended on the length of the closed road sections and the time necessary to inspect the sections for possible rockfall after the detonation.

There were six roadblocks used to isolate the Morrisania Mesa area. These were activated at H-4 hr and were lifted at H+6 hr. While these were not concerned with the possible danger of rockfall, they were a safety precaution and denied access to an area by vehicle traffic. The long time duration of these six roadblocks resulted in confusion and bad feelings among the local people who wanted to return to their homes.

J. OBSERVER PROGRAM

An Observer Program may be beneficial in providing publicity for the event but care should be taken to allow more time for site visits. Another problem was the weather delays as many of the observers had prior commitments and had to leave before the detonation actually took place. If a weather dependence of the Rulison type is connected with the detonation, then the Observer Program should be deleted. The approximate cost of the Observer Program was $33,000.

K. MINE EVACUATION

Initially, the evacuation of mines was considered for a limited radius with one exception; that being the Dutch Creek Mine which is considered to be very gaseous. It was considered politically expedient to include five mines (including the Somerset Mine) at a greater distance in the evacuation list. Unfortunately, the Somerset Mine evacuation involved 200 men on a 3-shift basis. The United Mine Workers maintained that no shift could be treated any differently than any other so all three shifts remained off on D-day.

L. PREDETONATION COSTS ASSOCIATED WITH DAMAGE

A number of items were costed predetonation to eliminate, disprove, or reduce claims which might be generated because of damage created by the event. This included first order surveys of Battlement and Harvey Gap dams, location of additional seismic stations, and documentation of homes, mud pits, mines, and wells pre- and postdetonation. Some of this was necessary; however, the criteria used should be reevaluated.

12. SCHEDULE OF EVENTS

Figure 3 shows the schedule of the major events of Project Rulison from the completion of the Emplacement Well in January 1969 to the postdetonation rollup in October 1969.

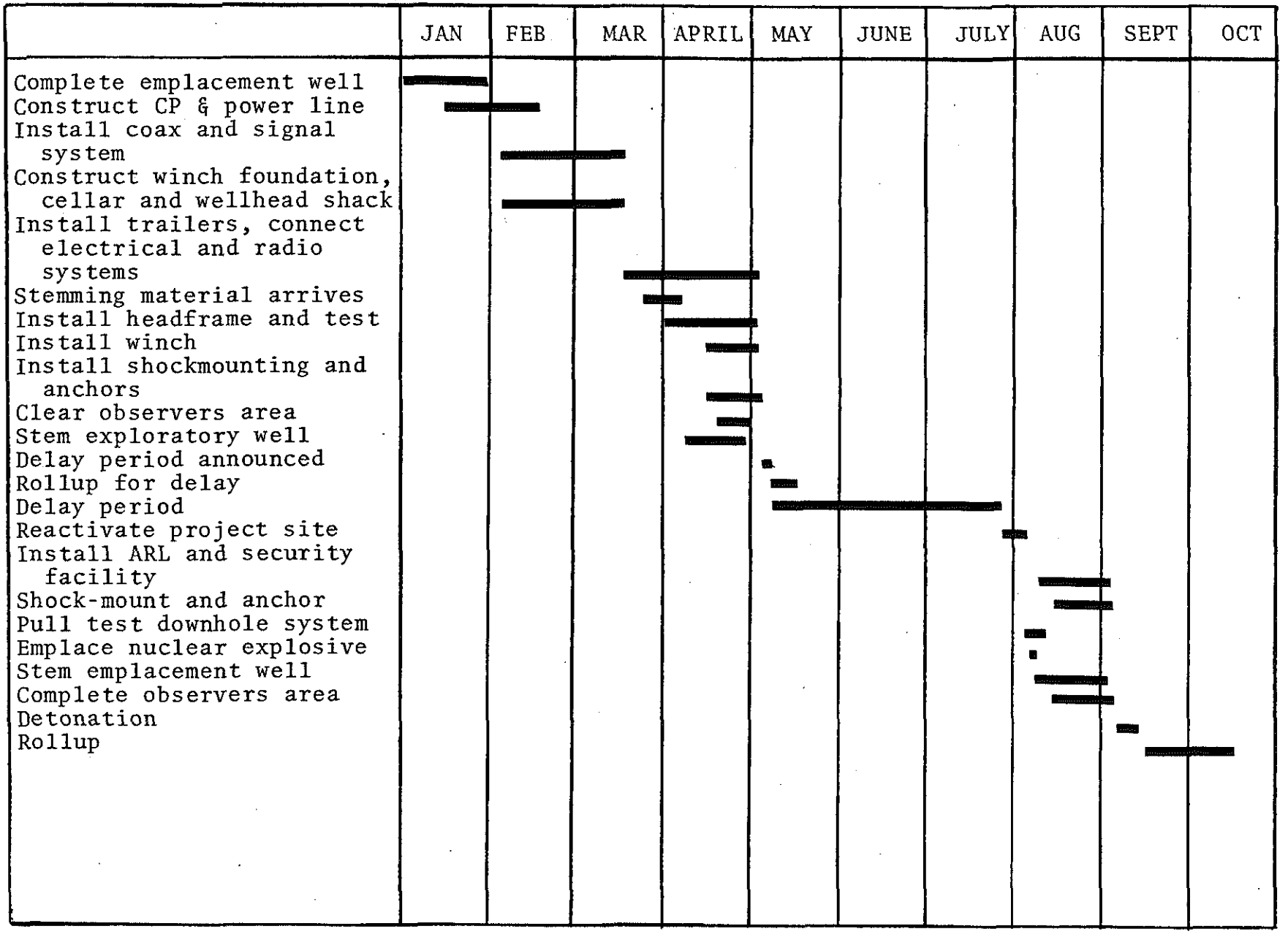

Figure 3. Schedule of Events, 1969.

APPENDIX A
RULISON REPORTS

This appendix contains synopses of the reports concerning Project Rulison except for those dealing with reentry.

ORGANIZATIONAL ABBREVIATIONS

The following abbreviations are used in crediting the organizations that produced the reports:

AOC	Austral Oil Company Incorporated
BMI	Battelle Memorial Institute
BuMines	Bureau of Mines
CER	CER Geonuclear Corporation
C of E	Corps of Engineers
ERC	Environmental Research Corporation
ESSA ARL/LV	Environmental Sciences Services Administration, Air Resources Laboratory, Las Vegas
F&S	Fenis & Scisson
I. I.	Isotopes, Incorporated
JAB	John A. Blume & Associates
LASL	Los Alamos Scientific Laboratory
NVOO	Nevada Operations Office
SSWC	H. Bolton Seed, James L. Sherard, and Woodward-Clyde and Associates
SWRHL	Southwestern Radiological Health Lab, United States Public Health Service
UKAEA	United Kingdom Atomic Energy Authority
USC&GS	United States Coast & Geodetic Survey
USGS	United States Geological Survey

GEOLOGY AND HYDROLOGY OF THE PROJECT RULISON EXPLORATORY HOLE

PNE-R-2, USGS, April 1969

The Project Rulison site is on the southwest limb of the Piceance Creek Basin, a large northwest-trending structural downwarp in northwestern Colorado. Beds penetrated by the R-EX hole dip northeastward at 2° or less.

The R-EX hole penetrated the following formations in descending order: Alluvium, Green River and Wasatch Formations of Eucene age, an unnamed unit of Paleocene age, Ohio Creek Conglomerate of Paleocene (?) age, and Mesaverde group of late cretaceous age.

The principal surface hydrologic feature of the Project Rulison site is Battlement Creek, which carries most of the runoff to the Colorado River. Some runoff is diverted for irrigation and some infiltrates the stream alluvium and terrace deposits and appears as springs in several places downstream from the Project Rulison site.

The ranches on Morrisania Mesa obtain their domestic and livestock water from shallow wells in the alluvium and ponds which obtain their water from Battlement Creek and other small streams and springs.

The groundwater resources are confined primarily to the alluvium and terrace deposits as the underlying bedrock formations are generally impermeable and yield little or no water.

All zones in R-EX below the unnamed unit of Paleocene age that yielded any water during drilling or zones interpreted from geophysical logs as likely to contain water were evaluated by drill-stem testing techniques.

A small amount of water was found in an upper Mesaverde sandstone lens during the drilling of R-EX but later tests of this zone and other zones thought to contain water in the Mesaverde showed no measurable water production. Several deep drill holes in the Ohio Creek Conglomerate above the Mesaverde group in the Rulison Gas Field have produced no water. The sandy zones in the middle and the upper parts of the Wasatch Formation produced no water, but the lower Green River Formation, about 5,000 feet above the WP of the nuclear device, has some sandy zones that produced water in sufficient quantities to make air drilling difficult.

PRE-EVENT BIOENVIRONMENTAL SAFETY SURVEY AND EVALUATION

PNE-R-3, BMI, July 1969

The pre-event ecological survey of the Project Rulison area was made with two primary objectives: 1) to determine the range livestock and wild game populations of the area and the seasonal distribution of livestock and game in the area immediately surrounding SGZ, and 2) to identify any significant adverse ecological consequences that might result from carrying out the project.

Grazing range on the National Forest land is provided for approximately 8,950 "cattle units*" from mid-June to mid-October. Approximately 2,300 units lie within 15 miles east and southeast of SGZ. About 6,650 units lie in the same general direction between 15 to 30 miles from SGZ. Transitory grazing is provided by the adjoining BLM and private lands at lower elevations which extends the grazing period approximately 2 weeks on each end of the season.

The Project Rulison site is located within Colorado Game Management Unit No. 42, which is the second most productive western mule deer harvest area in the state. Time of migrations are from mid-April through mid-May and late October through November. The bow and arrow hunting season is from August 16 through September 14 with the regular hunting season from October 18 through November 6.

Battlement Creek is a source of drinking, stock, and irrigation water for the inhabitants of Morrisania Mesa. Three water samples were collected in the vicinity of SGZ for analysis. Sample No. 1, the control sample, was taken from the main Fork of Battlement Mesa which is isolated from the drill site by a ridge. Samples No. 2 and No. 3 were taken from the east Fork and a tributary downstream from SGZ, respectively.

Battlement Creek is also a trout stream. The stream is fished, but not heavily, as are the Battlement reservoirs that feed into Battlement Creek.

No hazard was expected but in the event of accidental radionuclide release, cattle and wildlife in the downwind sector could have conceivably accumulated radionuclides by inhalation or by ingestion of contaminated forage and drinking water. An assessment would have had to be made to determine that meat products from the animals would have been acceptable for human consumption.

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*1 unit = 1 cow and calf or 1.3 to 1.5 yearlings.

EFFECTS EVALUATION FOR PROJECT RULISON

PNE-R-4, NVOO, June 1969

The Effects Evaluation report contained the formal review of the Rulison Project made prior to the event by the Test Evaluation Panel and the Safety Panel of Consultants of the Nevada Operations Office. The Test Evaluation Panel reviewed the possibility of the release of radioactivity to the atmosphere. The Safety Panel reviewed the predicted ground motion, structural response, slope stability, hydrology, and ground water contamination effects.

The evaluation of the hazards associated with the Rulison event was used to develop procedures to assure that the detonation would be conducted safely. These procedures were reflected in the Project Rulison Safety Plan.

PREDICTIONS OF SEISMIC MOTION AND CLOSE-IN EFFECTS

PNE-R-5, ERC, August 1969

This report contains the predictions of seismic motion and close-in effects for the Project Rulison event, development of prediction methods, and pertinent geologic data. Some of the major features of the report are:

1. Predictions of peak particle motion for selected locations.
2. Predictions of distances to peak particle motions of 0.1 g and 0.001 g (accelerations).
3. Predicted pseudorelative velocity (PSRV) spectra at selected stations.
4. Geologic environment.
5. Development of seismic prediction method.
6. Predictions of cavity, cracking, and gamma-radioactivity radii.
7. Predictions of chimney height and surface spalling.

RECORDS OF SELECTED WELLS AND SPRINGS IN THE RULISON PROJECT AREA

PNE-R-6, USGS, August 1969

An inventory of wells and springs in the Project Rulison area and vicinity was made from March 20 to April 3 and May 20 to 25, 1969. The purpose was to document the physical condition of the wells and springs and to collect samples of water prior to the nuclear detonation for chemical analysis. During the inventory all wells and springs within a 10 kilometer (6.2 mile) radius of SGZ and selected wells and springs within the 10 to 20 kilometer (12.4 mile) radius were visited for a total of 110 water sources. Depths were measured where possible and the quantity of water discharged measured by the "bucket and stopwatch" method or by using a parshall flume. Information regarding the construction of wells and the improvement of springs was collected. The water temperature was recorded and samples collected and analyzed for ph, total alkalinity, specific conductance, and turbidity. Selected samples were analyzed for general chemical and radiochemical constituents.

PRE-SHOT R-EX WELL TEST DATA

PNE-R-7, AOC, October 1969

Drilling of R-EX was started November 9, 1967, in the SW-1/4, Section 25, T7S, R95W, Garfield County, Colorado. The well was drilled to a total depth of 8,516 ft, 7-5/8-in. intermediate casing was set at 6,367 ft, and a 5-1/2-in. liner set at 8,514 ft.

Eleven conventional cores were taken, six in the Wasatch and five in the Mesaverde formations. Fourteen side wall cores were taken, of which 12 were recovered. Drill stem and flow tests were conducted at selected intervals.

The Mesaverde formation was perforated in four selected intervals from 7,302 to 8,464 ft. Individual tests were run in each interval. Flow and build-up tests were run over the entire gross section. Results of these tests indicated severe formation damage was present throughout the interval. During September 1968, three separate temperature surveys were run.

To determine true formation charactertistics from flow and buildup tests, a typical interval (8,140 to 8,172 ft) was isolated and given a small volume fracture treatment so that the true reservoir properties beyond the damage radius could be evaluated. The fracture treatment consisted of 5,500 lb of 20/40 mesh sand and 5,500 lb of glass beads.

After completion of the fracturing treatment on 10/05/68, the well was flowed until 10/11/68 to allow it to clean up. The well was shut-in from 10/11/68 to 10/16/68 for buildup prior to testing. From 10/16/68 to 10/23/68, attempts were made to test the well but equipment failures negated this effort. On 10/23/68, Flow Test No. 1 was started but was terminated on 10/29/68 due to wellbore mechanical problems.

The well was shut-in for Buildup No. 1 from 10/29/68 to 11/14/68 at which time the well was blown down to change out the tubing and install the tree. A leak around the pipe rams on the BOP's occurred after about 360 hours of the buildup, and the leak continued for the remainder of the buildup test. The bottom hole pressures were obtained using a Ball Brothers Pressure Sentry MK-9P, 0-3000 psi element, landed at 8,000 ft KBM.

Due to mechanical problems occurring during the test period and also because the duration of the test was not sufficient to allow evaluation of the true formation characteristics, a second flow period and buildup period was necessary.

The well was shut-in from 11/14/68 to 12/12/68 at which time Flow Test No. 2 was initiated as a constant rate drawdown test at an average rate of 32.6 MCFD. The Ball Brothers surface recording bottom hole pressure gauge was used along with a deadweight surface pressure measurement. The flow test was terminated on January 9, 1969, and Buildup No. 2 was recorded from January 9 to March 15, 1969 at which time testing ended.

EMPLACEMENT AND CEMENTING OF HOLE 25-95A (EMPLACEMENT HOLE)

PNE-R-8, F&S, 1969

A string of 10-3/4-in. casing was placed to a total depth of 8,701 ft Kelly Bushing (KB) and cemented in 3 stages. Cement quality was verified using an acoustic bond log and a density log.

The package envelope, 5.2 ft long and containing boron carbide in its annulus, was included in the 10-3/4-in. casing string so as to be in the Mesaverde section at 8,442.5 ft (KB). Inside the 10-3/4-in. casing, the cement was drilled out to a depth of 10-1/2 ft below the centerline of the boron carbide envelope. This total depth was confirmed to be 8,453 ft (KB) by wire line measurements and a casing collar locator.

A 900 cubic feet per minute air compressor was used in conjunction with gas lift valves, appropriately placed in a string of 2-3/8-in. tubing, for the removal of all fluid from the 10-3/4-in. casing. Dryness of the casing was tested by dumping a 100-lb sack of micro-cel in the annulus between the 2-3/4-in. tubing and 10-3/4-in. casing and observing the dust ejected from the "blooie" line.

Strength of the cement plug in the 10-3/4-in. casing at 8,453 ft (KB) was tested by applying a load of 84,000 lb. Diameter uniformity and casing straightness were checked by running a 9-in. diameter, 15-ft long mandrel to the total depth of 8,453 ft (KB). Dryness was double checked by a bailer filled with sample sacks of micro-cel and run on sand line to 8,453 ft (KB). Smoothness of the cement top in the casing was inspected by a 9-in. diameter lead impression block with 20,000 lb of applied pressure.

RADIOACTIVITY IN THE HYDROLOGIC ENVIRONMENT

PNE-9, I. I., August 1969

In the absence of specific information on the hydraulic and chemical-exchange properties of the rocks at the Project Rulison Site, conservative estimates were made in order to make contamination predictions. Source term concentrations for tritium and strontium-90 were assumed to be 6×10^{-2} to 2×10^{-1} uCi/ml and 4×10^{-2} to 1×10^{-1} uCi/ml, respectively. Assumption of high but credible water movement rates and reasonable retardation effects indicates that neither tritium or strontium-90, for example, would move more than a few miles before decay or dilution to below CG* levels. In the unlikely event of mass movement of radioactivity upwards to the land surface, transport of nuclides rates might exceed those at depth but greater-than-CG levels of activity are not expected at any known water use point.

*CG is an abbreviation for Concentration Guides. CG's are reference concentrations as given in November 8, 1968, revision of USAEC Manual, Chapter 0524. Standards for Radiation Protection Annex A, Table II, Column 2, reduced by a factor of three to be consistent with standards applicable to Individuals and Population Groups in Uncontrolled Areas. These guides are applied as per instructions in TN NV 0500-23, dated May 12, 1969. A CG is used in the same context as was an MPC previously.

OFF-SITE RADIOLOGICAL SAFETY AND RESIDENT EVACUATION PROGRAM

PNE-R-14, SWRHL, January 1970

Although it was extremely unlikely that a venting of radioactive material would occur as a result of the detonation, the Public Health Service (PHS), Southwestern Radiological Health Laboratory (SWRHL), conducted an off-site radiological safety program for the detonation phase of the experiment. In cooperation with the CER Geonuclear Corporation, the PHS also arranged for resident evacuation and other precautions in the area to minimize any possible hazard which might result from ground motion produced by the detonation.

The off-site radiological safety program included operating a system of environmental surveillance networks in the Project Rulison area, and fielding radiation monitoring teams in the off-site area for the detonation. The surveillance networks consisted of a radiation dosimetry network, sampling networks for air, milk, water, and vegetation, and collection of milk cow feed, animal tissue, and natural gas samples. The surveillance networks were supplemented on detonation day with monitoring aircraft and ground monitors carrying portable environmental sampling and monitoring equipment.

The basic criteria for off-site radiological protection were those contained in Section II-A of the Appendix to the AEC Manual, Chapter 0524.

The off-site environmental surveillance program indicated no radioactivity was released to the environment from the detonation. The dosimetry network and air, milk, and water sampling networks were operated prior to and following the detonation and showed no changes in environmental radioactivity levels. Aerial monitoring over the test well and ground monitoring in the off-site area with portable radiation survey instruments on the day of the detonation also showed no radioactivity above background levels.

Based on predicted ground motion in the vicinity of the test well as a result of the nuclear explosion, residents within 5 miles of the test well were evacuated from the area for several hours on D-day during the detonation period, and gas and electrical utilities in the area were disconnected to minimize fire hazards. PHS representatives remained in the area with five families who chose to remain at home.

Arrangements were made for all residents in the area between 5 and 9 miles from the test well to be outdoors and away from structures at detonation time to minimize any possible hazard from falling objects or structural damage. A uranium and vanadium ore processing mill and two schools beyond the 9-mile radius were also evacuated.

The resident evacuation program was successfully carried out with no accidents, injuries, or health problems observed by or reported to the PHS prior to or after the Project Rulison detonation.

CHEMICAL AND RADIOCHEMICAL ANALYSIS OF WATER FROM STREAMS, RESERVOIRS, WELLS, AND SPRINGS IN THE RULISON PROJECT AREA

PNE-R-15, USGS, January 1970

As part of the testing of the Project Rulison gas reservoir characteristics, natural gas from the test hole will be burned. The water vapor from this gas will contain tritium and the resultant changes in the tritium concentration in the water of the project area will be determined.

An inventory of wells and springs in the Rulison project area was made from March 20 to April 3 and from May 20 to May 25, 1969, by the U.S. Geological Survey. The purpose of the inventory was to document the physical condition of the wells and springs and to collect samples of water for chemical analyses.

Following the detonation of the project device, some wells, springs, and cisterns were investigated as a result of damage complaints.

OBSERVED SEISMIC DATA

PNE-R-16, ERC, November 1969

This report presents the results of the processing of the observed ground motions from the Project Rulison event. The observed peak particle amplitudes as a function of distance are compared with predictions based upon a 40-kt yield. The observed 5-percent horizontal component pseudorelative velocity (PSRV) spectra (peak response) are compared with the 40- and 60-kt spectral predictions.

Data were recorded at 36 instrument stations by United States Coast and Geodetic Survey and processed by Environmental Research Corporation.

STRUCTURAL EFFECTS OF THE RULISON EVENT

PNE-R-17, JAB, December 1969

This report presents the preliminary data concerning the structural response effects from Project Rulison.

A limited evaluation of the currently available data indicates that the predetonation predictions of damage occurrence were generally accurate. Most of the damage reports from locations close to ground zero cited either plaster cracking or chimney damage. The ground motion perceived by observers close to the GZ was felt primarily as a vertical motion, the horizontal component being felt at more distant locations.

Since complete ground motion spectra and damage data were not available at the time of this report, only tentative analyses and conclusions could be made of the effects of the event. Later reports will contain the more complete results of the analyses and evaluations.

SEISMIC MOTIONS FROM PROJECT RULISON

PNE-R-18, ERC, January 1970

Seismic measurements from the Rulison event are shown and compared with experimentally and analytically derived pre-event estimates. Seismograms, peak accelerations, and response spectra are given along with a description of the associated geologic environment.

Techniques used for the pre-event estimates are identified with emphasis on supportive data and on Project Rulison results. Of particular interest is the close-in seismic frequency content which is expected to contain stronger high-frequency components. This higher frequency content translates into stronger accelerations within the first tens of km, which in turn affect safety preparations.

Additionally, the local geologic structure at nearby population centers is considered. Pre-event reverse profile refraction surveys are used to delineate the geology at Rifle, Rulison, Grand Valley and other sites. The geologic parameters are then used as input to seismic amplification models which deliver estimates of local resonant frequencies. Prediction of such resonances allows improved safety assurance against seismic effects hazards.

THE EFFECTS OF THE RULISON EVENT ON BUILDINGS AND OTHER SURFACE STRUCTURES

PNE-R-21, JAB, January 1970

This report was an interim report of the then currently available data.

The geographical distribution of towns, dams, and major population centers with regard to the Rulison site is illustrated. Structure distribution is discussed including structure type, construction materials, and zone (0 to 5 km, 5 to 10 km from Emplacement Well, etc.).

Damage predictions and safety recommendations were developed using data provided by ERC. The safety recommendations included the evacuation of inhabitants. Within 35 km of the Emplacement Well, all structures were located, inventoried, and evaluated for possible damage. A predetonation report was prepared with recommended structural repair and bracing recommendations.

By the first week in January 1970, 251 damage complaints from the area within 35 km of the Emplacement Well had been analyzed. The results are presented in several tables.

By the end of 1969, more than 90 percent of the damage claims had been settled at a total cost of approximately $55,000.

RADIOACTIVITY IN WATER

PNE-R-22, I. I., February 1970

The Project Rulison detonation was completely contained, as planned, within the Mesa Verde Formation. Radioactivity produced by the explosion was initially distributed non-uniformly in the collapsed chimney and fractured rock surrounding the working point. Any mobile water below 7,000 feet in the Mesa Verde Formation that becomes contaminated is expected to move downward or laterally but not upward. However, hydrologic testing data indicates that the rate of movement will be low enough and chemical exchange retardation high enough that nuclides in greater than CG* concentrations will not be transported for any significant distance. In fact, the ground water in the Mesa Verde Formation may be immobile, in which case, all radioactivity will reside and decay where it was initially emplaced.

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*CG is an abbreviation for Concentration Guides. CG's are reference concentrations as given in November 8, 1968, revision of USAEC Manual, Chapter 0524. Standards for Radiation Protection Annex A, Table II, Column 2, reduced by a factor of three to be consistent with standards applicable to Individuals and Population Groups in Uncontrolled Areas. These guides are applied as per instructions in TN NV 0500-23, dated May 12, 1969. A CG is used in the same context as was an MPC previously.

RULISON SEISMIC EFFECTS

PNE-R-23, USC&GS, February 1970

The special projects party of the United States Coast and Geodetic Survey recorded the Project Rulison seismic signal within the range of 4.29 km to 366.3 km at 44 seismograph stations located in 4 states. Of the stations, 84 percent were located within a 145 km radius and 14 percent located within the 230 km to 366.3 km radius from the GZ. Station No. 44, located in Salt Lake City at a range of 366.3 km, was the most distant station.

The seismic instrumentation effort had the following objectives:

1. To determine the rates of attenuation with distance of the maximum earth particle velocity.

2. To determine any azimuthal variations of ground motion.

3. To instrument various locations to record motion of the ground for a possible claim evaluation in the event that damage resulted from the detonation.

4. To make pre-event and post-event earthquake investigation studies to determine the seismicity before and after the event.

Three types of seismograph instruments were used. Of the 44 stations, 31 were instrumented with the L-7, 12 with the L-7D, and 1 with the S-13. The S-13, with a capability of obtaining magnifications exceeding one million, was used primarily for the earthquake investigations. Out of the 44 stations instrumented, 5 were partially lost and 2 were completely lost, giving an operational success of 84 percent.

The recorded high-frequency particle velocities were as predicted. The best general expression for the maximum trace earth particle velocities recorded on hardrock satisfied the following formula:

$$V = 547\ R^{-1.92}$$

Readily identifiable impulsive elastic waves with their arrival times are given in the final report. The average proportional velocity of 5.22 km/sec for the initial p-phase was calculated in a range of 4.29 km to 366.3 km.

The earthquake occurrence rate of 0.7 earthquakes per day during the two months of recording after the event compared favorably with the 0.6 earthquakes per day average prior to the event.

Descriptions, photographs, and maps showing the location of each seismograph station are given in the final report.

GEOHYDROLOGY

PNE-R-24, USGS, March 1970

Surficial deposits, the only source of usable ground water near the Rulison site, are inconsequential and are far above the top of the rubble chimney and fractured zone created by the detonation. Therefore, the hydraulic testing in the Project Rulison Exploratory Well was limited to deep, bedrock formations below the unnamed unit of the Paleocene Age. Tests showed negligible or no fluid entry to the well, which indicates that ground water flow in the Rulison site is nil.

Seismic effects of the Project Rulison nuclear detonation caused a hydrostatic pressure pulse in the two monitored wells at distances of 3,660 meters (12,000 ft) and 6,100 meters (20,000 ft) from the SGZ.

In response to the Project Rulison event, the discharge of Battlement Creek recorded at the U.S. Geological Survey gaging station increased slightly immediately after the detonation. The discharge at the gaging station 1 hour and 30 minutes after the detonation increased abruptly from 4.5 to 14 cubic feet per second, and then began a gradual decline. Precipitation in the drainage basin, beginning nearly 2 hours after the explosion, obscured any later effects of the Rulison event.

In no case was there any indication that the streams or the water-bearing formations in the vicinity of the site had been permanently impaired as a result of the Project Rulison detonation.

Analyses of water collected postdetonation from 21 surface-water sampling points in and near the Project Rulison site indicated that the nuclear detonation had no effect upon the chemical characteristics of the water. Analyses of spring water collected postdetonation also indicated that the nuclear detonation had no permanent effect upon the chemical characteristics of the water.

POST-EVENT BIOENVIRONMENTAL SAFETY ASPECTS

PNE-R-25, BMI, January 1970

Approximately 6 months prior to detonation, an ecological survey was made of the area to ascertain the seasonal distribution of range livestock and wild game in the area, and the distribution and use of water from the Battlement Creek watershed. This information was needed to plan protective measures in the event of accidental release of radionuclides and to identify any potential adverse ecological effects from site operations or from the detonation.

The only significant potential problem identified during the pre-event survey was the possible contamination of the Battlement Creek by oil, drilling muds, and drill cuttings remaining at the drill sites. However, prior to detonation, most of the oil and drilling wastes were removed from the mud pits nearest the emplacement well and hauled away. The pits were then filled and leveled. The small amount of oil and drilling mud remaining was contained behind a large dike.

Since there was no radioactivity released to the environment by the detonation, no assessment of radionuclide burdens in livestock or game animals was considered necessary.

Effects of the Project Rulison detonation on the surrounding ecosystem were minimal and no significant adverse effects were noted during the post-event observation.

WEATHER PREDICTIONS AND SURFACE RADIATION ESTIMATES

PNE-R-26, ESSA ARL/LV, January 1970

This report covers the preliminary climatology for western Colorado and includes general information on surface winds at the Project Rulison site.

The "winds aloft" hodographs are based upon data for Grand Junction, the nearest existing upper air sounding station. They are considered representative of the general Project Rulison area.

At Grand Valley, near the Project Rulison site, the Colorado River valley is oriented nearly east-west. A definite drainage condition exists in the valley with the air draining to the west at night and blowing up the river valley during the daytime. The average turn-around time is 1200 MST but can be as early as 0800 MST and as late as 1500 MST.

For measuring surface winds at the Project Rulison site, four wind towers were installed. Wind tower number 1 was located on the south side of the Colorado River valley. The flow at this tower is complicated by the mountain-valley winds which flow from the Project Rulison SGZ area. Wind towers number 2 and 3 were located in a mountain valley which is oriented nearly north-south. Wind tower number 4, located on Battlement Mesa at approximately 10,000 feet MSL, was in a flow similar to the 700 MB winds for Grand Junction, Colorado.

Even though the Project Rulison experiment was designed and conducted so that venting of radioactive products to the surface was not expected to occur, the event was to be executed only when the wind direction was toward a sector which satisfied the requirements specified in the Operations Safety Plan.

On D-day, hourly surface and pilot balloon observations were taken at the Project Rulison Control Point (CP), at three locations near the Project Rulison site, and at Grand Junction to furnish continuing and intensive surveillance of changing meteorological conditions at the surface and aloft. The Director of Nuclear Operations (DONO) and his advisory panel were kept informed of the meteorological situation starting with the morning readiness briefing in Grand Junction and continuing at the CP throughout the day.

Four surface wind towers, located near the SGZ, provided automatic measurements of surface windspeed and direction. These measurements were radiotelemetered to a master station at the CP. A 24-hour weather observing station, equipped to take upper-air soundings of wind, temperature, humidity, and pressure along with surface observations, was in operation in the CP area for 15 days prior to the event. Local and national network meteorological data and forecasts were available at the U.S. Weather Bureau Station, Walker Field, Grand Junction, Colorado.

Event-oriented forecasts of winds, weather, vertical atmospheric stability, and air trajectories were presented to the Director of Nuclear Operations and his Advisory Panel in daily formal and informal briefings beginning at D-7 days. Recognizing the possible, though unlikely, release of radioactivity into the atmosphere, estimates of potential radiation effects were also presented at each briefing.

D-day meteorological data, included in the report, show that the winds would have transported any released radioactivity toward the predicted direction.

ANALYSIS OF GROUND MOTIONS AND CLOSE-IN PHYSICAL EFFECTS

PNE-R-27, ERC, April 1970

This report relates the characteristics of the observed ground motions and close-in physical effects at specific recording stations to source, transmission path, and station site variables. Functional analyses performed toward this objective were:

1. Numerical simulation of close-in physical effects, such as cavity radius, cracking radius, and the energy input into the elastic region.

2. Comparison of the peak amplitude of ground motion and the pseudo-relative velocity (PSRV) spectral response observed at selected recording stations with the corresponding parameter of ground motion expected on the basis of Nevada Test Site (NTS) experience and the experience gained from analysis of the ground motions from the Gasbuggy detonation.

3. Comparison of the duration of the seismic energy observed from Project Rulison with that observed from Gasbuggy and from events at NTS.

4. Assessment of the adequacy of scaling theory to predict the amplitude and frequency composition of the ground motions expected from an overburied detonation in a sedimentary basin.

5. Identification of the elastic wave types observed on seismograms from Project Rulison and determination of the contribution of each wave type to the observed peak particle ground motion.

6. Determination of the specific dissipative (Q) characteristics of the earth's crust in the Piceance Basin.

7. Determination of the frequency dependent amplification experienced at local sites and assessment of the adequacy of the techniques employed to predict its characteristics.

8. Calculation of the seismic energy efficiency of the Project Rulison detonation and a comparison with that determined from Gasbuggy and selected NTS detonations.

9. Specification of the properties and characteristics of the geologic environment of the source, transmission path, and recording site.

The primary conclusions of the report are:

1. The level of the peak vector velocities and displacements observed from Project Rulison agree with the predicted levels. However, the peak vector accelerations are slightly higher than predicted. The observed peak vector accelerations and velocities significantly exceed the level expected from a normally buried 40-kt contained device detonated on the Nevada Test Site.

2. The PSRV spectra calculated from Project Rulison ground motions agree well with the spectra predicted on the basis of scaling theory, accounting for differences in yield and device depth of burial. The peak spectral response exhibits a higher level and occurs at shorter periods (0.1 to 0.4 second) than that of the spectral response expected from a normally buried 40-kt contained device detonation on the Nevada Test Site.

DYNAMIC AND STATIC RESPONSE OF THE GOVERNMENT OIL SHALE MINE AT RIFLE, COLORADO

PNE-R-28, BuMines, February 1970

The purpose of this instrumented study was to determine changes in roof or pillar displacement, the microseismic noise rate, and the roof and pillar vibrations resulting from the ground motion from Project Rulison.

Because the mine roof is old and there is evidence of questionable stability, there was reason to believe that the ground motion from Project Rulison would create an unstable condition, especially if the motion were to cause resonant vibrations in roofs or pillars.

The measurements were performed to detect both dynamic and static response to the motion. Static roof displacements were measureed at seven locations and static changes in roof strain measured at three places. Static changes in pillar displacement were measured at four locations. The microseismic noise rate was monitored by 15 geophones located throughout the mine. Of these geophones, seven were used in an effort to locate sources of microseismic disturbances. Roof and pillar vibrations were measured by six geophones individually arranged to measure vertical or horizontal response.

The analyses of the data leads to the conclusion that the mine responded to the ground motion generated by Project Rulison. The microseismic and vibration data show that the mine vibrated and generated microseisms; however, the response was back to normal within 8 to 10 sec. The maximum acceleration, displacement, and particle velocity was 422×10^{-1} in./sec^2, 241×10^{-4} in., and 754×10^{-3} in./sec, respectively; these values were measured from a geophone located on a roof with a 60-ft span and in a crosscut. This roof geometry represents the condition for least roof support in the mine.

The results of this study are that if any damage was created by the ground motion, the damage was too small to be seen or measured with these instruments.

HARVEY GAP DAM SAFETY STUDY

PNE-R-30, SSWC, May 1969

The Harvey Gap Dam, an old earth dam located about 30 kilometers from the Project Rulison SGZ, would be affected by the ground motion produced by the Project Rulison detonation. Since a failure of the dam could cause considerable property damage and possible loss of life, it was considered desirable to carry out studies to evaluate its present condition.

From the results of the field explorations, the information gathered concerning the construction and past performance, and the present appearance, it was concluded that the structure was relatively stable with a satisfactory margin of safety as measured by any reasonable engineering standard.

From a consideration of all of the factors involved, it was reasonable to conclude that the ground motions resulting from the Project Rulison event were unlikely to cause any significant damage to the dam. However, the possibility of some slumping and/or cracking of the crest of the dam, while most unlikely, could not be excluded and, in view of the very low freeboard and the erodible nature of the downstream slope, could lead to a release of water from the reservoir. Accordingly it was recommended that the following precautions be taken:

1. The water level in the reservoir should be lowered to at least 10 feet below the crest of the dam before the explosion.

2. If the water level in the reservoir is 10 feet below the crest of the dam at the time of the explosion then:

    a. Provisions for rapid sealing of any cracks which might develop should be made; these might involve simply the provision of adequate stockpiles of sand and gravel and a means for dumping this material in areas needing repair.

    b. Evacuate people from areas downstream which might be flooded if conditions deteriorate and water is released from the reservoir.

3. If the water level in the reservoir is 15 to 20 feet below the crest of the dam at the time of the explosion it would be unnecessary to provide remedial measures for any damage that might occur but provisions should be made for timely evacuation of people downstream of the dam if the damage should impair the safety of the dam.

4. Regardless of the water levels at the time of the explosion, careful observations of the displacements of the crest of the dam should be made both during and following the explosion. In addition the transient ground motions at the abutments of the dam, at the crest of the dam, and at the ground surface beyond the downstream toe of the dam should be recorded. These observations would help materially in evaluating the performance of this and other dams during future nuclear detonations.

CER GEONUCLEAR'S PARTICIPATION IN THE SAFETY PROGRAM

PNE-R-31, CER, July 1970

CER Geonuclear was responsible for the mine and quarry evacuation program, the census, medical survey and detonation-time building evacuation of the communities of Grand Valley and Rulison, and the turning off and on of the service utilities to all houses within the 5-mile radius of SGZ.

A total of 24 mines and quarries were evacuated or were determined to be inactive at detonation time out to a radius of 43 miles from SGZ.

All of the buildings within the communities of Grand Valley and Rulison were evacuated without incident with the help of the Garfield County Sheriff's Posse.

To further minimize the remote possibility of fire if gas lines or electrical wiring were damaged by the Project Rulison ground motion, service utilities to 42 homes were turned off prior to the event. After the event, the service systems were checked for damage, repaired where necessary, and service restored. Damage was minimal and somewhat questionable as to being event-caused.

SEISMIC ACTIVITY IN SEPTEMBER 1969 NEAR THE RULISON NUCLEAR TEST SITE

PNE-R-32, USC&GS, June 1970

The USC&GS Special Projects Party, monitoring seismic activity in the Project Rulison vicinity, detected no earthquakes within 100 kilometers of the SGZ during the predetonation period of September 3 to September 10.

Postdetonation monitoring was continued until September 30 with a total of 27 seismic events being detected. Fourteen of these were less than 100 kilometers from the SGZ and 9 were large enough to be adquately recorded. The largest local shock, occurring on September 13, had an approximate Richter magnitude of 2.3.

Meanwhile, a communication was received by NVOO in which 10 earthquakes were reported to have occurred between September 12 and September 27 of which 6 had assigned magnitudes ranging up to 4.0 on the Richter scale.

In order to resolve the wide disparity between reported magnitudes, the Special Projects Party felt it was necessary to recalibrate their instruments and recalculate the magnitudes.

The two types of seismic detection systems (Mark Products L-7 and Geotech S-13) used during the Rulison project were "shake-table" tested by the USC&GS Seismological Laboratory in Albuquerque, New Mexico. The derived curves from the S-13 systems agreed within $\pm$5 percent of the manufacturer's specifications. The derived curves of the L-7 Systems agreed within $\pm$5 percent of the theoretical and internal oscillator curves.

The magnitudes were recalculated using two procedures primarily for determining magnitudes, while a third method was used to verify the other results. The recalculated magnitudes were less than 3.0 in all cases and indicate the level of magnitudes were at least seven-tenths of amagnitude smaller than those reported in the communication to the AEC.

ON-SITE RADIOLOGICAL SAFETY REPORT FOR THE PERIOD APRIL 21, 1969 TO DECEMBER 31, 1969

PNE-R-35, EIC, April 1970

The depth of device burial, geological structure in the vicinity of the detonation, and the review of the casing, cementing, and stemming plan led the test evaluation panel to conclude that radioactivity would be contained. Although no release of radioactivity was expected, the policy of the Atomic Energy Commission is to assume the worst credible condition. A safety plan designed to protect the public and project personnel from such a contingency was included in the Project Rulison Operational Order, NVO-OPO-1-69.

Eberline Instrument Corporation was assigned by AEC/NVOO to support the Director of Nuclear Operations with radiological support services in accordance with the safety plan. This included site surveillance, effluent documentation, environmental sampling, radiological measurements, and personnel dosimetry.

Radioactive materials resulting from the Rulison event were completely contained as no evidence of any leakage was obtained from the above activities.

SOME SEISMIC RESULTS OF THE U.S. GASBUGGY AND RULISON UNDERGROUND NUCLEAR EXPLOSIONS

PNE-R-36, UKAEA, 1970

This report presents the results obtained from four United Kingdom Atomic Energy Authority sponsored seismic arrays. The arrays were located at Eskdalemmi, Scotland; Yellowknife, Canada; Ganribidanm, India; and Warramnga near Tennant Creek, Australia.

The report discussed detection threshold and depth estimates and includes a data table and the array recordings.

MINE AND WELL EFFECTS EVALUATION

PNE-R-39, BuMines, March 1970

The Project Rulison mine effects evaluation program was designed to identify, evaluate, and eliminate or control all potential hazards to mining operations in the general project area. In addition, the effects of the detonation on the operations were documented.

On a survey of the general area within a radius of 50 miles from SGZ, 24 coal, oil shale, limestone, and vanadium mines were identified and subsequently visited. The operators were briefed on Project Rulison and its predicted effects on their operations. Later, recommendations for the evacuation of the mines during detonation time were formulated and predetonation and postdetonation inspections were made of several of the closer mines where structural damage was possible.

Only 2 mines, the Cameo and Red Canon Coal mines at a distance of 27 and 32 miles, respectively, experienced structural damage at detonation time. The damage at Cameo could be attributed to the Project Rulison event while the relatively minor damage at Red Canon may or may not be. No significant damage was observed at any of the other nearby mines inspected nor was any damage reported by the operators of the fringe-area mines subsequently contacted.

Effects of the Project Rulison event on the closer mines were somewhat less, and on the farther mines somewhat more, than had been expected from predicted ground motions. Azimuthal variations in the ground motion may account for most of these effects, but the lack of adequate damage criteria also could be a significant factor. Better criteria obviously are needed for relating ground motion to mine damage, and more restrictive safety measures are suggested for future detonations until such criteria become available.

All gas wells and associated facilities within a 10-mile radius of SGZ were inventoried and those within the 5-mile radius were examined and photographed in detail, both pre- and postdetonation.

No surface damage from the Project Rulison detonation occurred to any of the field gas wells, the Project Rulison well (R-EX), or the Project Rulison emplacement well (RE). No subsurface damage was evident or suspected at field wells.

METHODS TO PREDICT GROUND MOTIONS FROM FUTURE UNDERGROUND NUCLEAR DETONATIONS IN THE PICEANCE CREEK BASIN, COLORADO

PNE-R-40, ERC, January 1970

This report describes methods for predicting the amplitude and frequency composition of the ground motions expected from proposed detonations in the Piceance Creek basin. The experience gained from Gasbuggy and Rulison, two detonations in sedimentary basins, are emphasized. In particular, the basic aspects of scaling theory, which account for the effect of yield and device depth of burial on the generated seismic motions, are highlighted. Predictions of the peak vector particle ground motions and the peak horizontal ground motions are made for three arbitrary detonations having yields of 40, 80, and 160 kt, and device depths of burial of 4,000, 6,000, 8,000, 10,000 and 12,000 feet. The pseudorelative velocity spectra are predicted for the same device yields and for device depths of burial of 4,000, 8,000, and 12,000 feet. These predictions, although somewhat generalized, illustrate the scaling technique and provide a useful basis for preliminary planning for future detonations in the Piceance Creek basin. These predictions can be applied for 12 specific sites in the Piceance Creek basin which recorded Rulison as well as for arbitrary sites described over the distance range of 10 to 60 km, provided the proposed detonation occurs in the same medium and has about the same location as the Rulison detonation. For different locations in the Piceance Creek basin, estimates of the ground motion predictions can be obtained by using the Rulison data contained in the report and applying scaling factors, displayed in graphical form, which account for changes in source to recording site distance, yield, and depth of burial.

YIELD ESCALATION EVALUATION

PNE-R-41, CER, 1972

This report provides the equations necessary to formulate seismic safety programs for future nuclear detonations in the Project Rulison area. Using these equations, it is possible to apply predictive techniques to estimate the damage to be expected from such explosions.

The safety criteria presented are those that were used by the Atomic Energy Commission on the Rulison event. The observed effects from the first Rulison detonation seem to indicate that the criteria are overly restrictive and that some relaxation could be made without increasing the safety hazard.

RADIOCHEMICAL ANALYSES OF WATER FROM SELECTED STREAMS, WELLS, SPRINGS, AND PRECIPITATION COLLECTED PRIOR TO REENTRY DRILLING

PNE-R-42, USGS, 1971

The U.S. Geological Survey established a water-sampling network in central and western Colorado on behalf of the U.S. Atomic Energy Commission to sample the hydrologic environment prior to and during the reentry drilling and the gas-production test phase of Project Rulison. Samples obtained from selected streams, wells, springs, and from precipitation are analyzed for tritium, gross alpha, and gross beta activity.

This report contains data from analyses of samples from the network collected prior to reentry drilling including sample data obtained both prior to and after the nuclear detonation. The data are intended to give representative values over approximately a 1-year period and to show variations in natural radioactivity.

A description of the procedures used in collection, analysis, and reporting of data is included.

PRE-SHOT INVESTIGATIONS AND SAFETY HAZARD EVALUATIONS

PNE-R-43, JAB, August 1969

This report presents the results of pre-event structural response investigations and evaluations of specific hazards associated with ground motion effects on buildings, hydraulic structures, and earth structures.

Included in the report are data on the seismicity of the event area, discussions of classes and evaluations of safety hazards, damage cost predictions, and a summary of locations which have been condition surveyed. An appendix presents correspondence and other information prepared during the work.

STRUCTURAL RESPONSE STUDIES FOR PROJECT RULISON

PNE-R-46, JAB, February 1971

Comprehensive structural response investigations were required for the detailed prediction of response and damage to natural and man-made structures in the area, to eliminate hazards to the public, and to provide a quantitative assessment of probable damage repair costs.

Structures respond to seismic ground motion as oscillating mechanisms with well-defined dynamic characteristics, and response prediction techniques have been devised accordingly. Methods are available for broad delineation of general damage patterns (the Engineering Intensity Scale), quantitative predictions of damage in various building classes (the Spectral Matrix Method), and individual structure threshold and degree of damage determinations (the Reserve Energy Technique and other evaluation methods).

Detailed surveys and field evaluations were necessary to provide the basic information required for the response and damage predictions. These included inventorying the structural population out to 25 kilometers, observation and evaluation of earth structure stability and hazards (including earth and rock slopes, earth dams, and canals), a brief seismic history study, and engineering evaluations and recommendations as to specific hazards and appropriate corrective measures.

Recommendations were provided for ground motion time-history instrumental recording. Mechanical gages for structure motion recording, crack movement measurement, and water wave observations were installed.

Damage to structures occurred generally as predicted. A delay of the original detonation date from May 1969 to September 1969 allowed slopes to dry out. As expected, there was an increase in stability, and little earth and rock slope movement occurred. Reservoir water levels were low, and some concern which had been expressed for the behavior of older earth dams was thereby eliminated.

The instruments used for the measurements consisted of particle velocity transducers (PVT) and particle acceleration transducers (PAT), and the measurements were recorded by oscillographs and tape recorders. Four Teledyne self-contained, strong-motion recorders were also used. A total of eight locations were used for motion measurement.

A summary of the maximum recorded ground motions at Rifle Gap Dam is included. The level of motion observed on the dam during the event was considered small; it was well below any failure level. The motion of the base of the dam was about the same as that measured on the natural

alluvium overburden materials downstream from the dam. The motion amplification factor between the base of the dam and the crest was considerably less than two. The Bureau of Reclamation took pre- and post-detonation survey readings on settlement markers on the slides and on the dam and found that no permanent displacements took place due to the Project Rulison event.

RULISON GROUND MOTIONS RECORDED AT THE TOSCO MINE AND TOWER STATIONS

PNE-R-51, ERC, July 1971

The TOSCO mine and tower seismogram records from Rulison have been processed and the 5-percent pseudorelative velocity (PSRV) spectra have been derived for the radial and transverse components of motion recorded at the mine and the vertical and transverse components recorded at the tower. The PSRV spectra for these components and copies of the seismograms for these stations are presented in this report.

STATISTICAL CORRELATION OF OBSERVED GROUND MOTION WITH LOW-RISE BUILDING DAMAGE

PNE-R-54, JAB, September 1971

A statistical study is conducted using the observed ground motion and structure damage data obtained from Project Rulison. The statistical analysis leads to identifying the ground motion characterization which best represents the damage potential of ground motion for low-rise buildings. A statistical model for predicting damage is presented. This model relates ground motion intensity to three damage prediction parameters: number of complaints, percentage of buildings damaged, and damage repair cost. A simple procedure for the application of the model to practical cases is discussed. The vector of the two horizonral components of response spectrum acceleration was determined as best representing the damage potential of ground motion for low-rise buildings.

PROJECT RULISON YIELD AND ^{85}Kr ACTIVITY.

LASL Memos,* May 1971

The total release of ^{85}Kr has been calculated as 1,112 curies. It is estimated that the explosion of the Rulison device created 25.8 $\pm$ 3.9 curies of ^{85}Kr per kt of fission yield. This estimate is based on fission yield and isotope decay information currently available in the open literature and on the assumption that the fissions were produced by fission-spectrum neutrons. It was further assumed that fission in ^{235}U were the only source of ^{85}Kr.

Therefore, the best estimate of the Project Rulison explosion yield is 43 $\pm$ 8 kt.

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*Bryant, Memo "^{85}Kr Activity Produced by the Rulison Nuclear Explosion," LASL, 4 May 1971.
Aamodt, Lee, Memo "Rulison Yield," LASL, 28 May 1971.

SEISMIC MONITORING OF THE RULISON UNDERGROUND NUCLEAR EXPLOSION NEAR RIFLE, COLORADO ON 10 SEPTEMBER 1969

USGS, February 1970

As a part of the USGS seismic investigation of the structure of the earth's crust and upper mantle, the seismic waves from the Project Rulison event were recorded by 30 seismic units along lines extending westward to the Pacific Coast and south-westward to Lake Isabella in California.

Five seismograph stations, located within 15 km of ground zero, monitored the Project Rulison seismic activity from H-72 hours until H+18 hours. No earthquakes were recorded preceding the detonation. Sixteen were recorded within the 43 minutes following the detonation; all had a Richter magnitude of less than 1 and all were located within 1 km of the explosion.

The fact that both compressional and dilational first motions were recorded for the 16 aftershocks indicates that a simple volume change did not cause the aftershocks as would have been the case for cavity relaxation.

MINE EXAMINATIONS
BuMines

Predetonation examination of 7 mines within a radius of 27 miles of SGZ was made and a postdetonation reexamination of these same mines was made as soon as possible after the event (between September 11 and 16, 1969). These examinations were made with one or more of the local federal coal mine inspectors. A representative of the operation was present during the pre- and postdetonation examination with the exception of the Roadside Coal Mine and the inactive Rifle Oil Shale Mine. In addition, a consulting mining engineer engaged by CER Geonuclear at the request of the operators, participated in the examinations of the Roadside and Cameo Coal Mines.

Pre- and postdetonation photographs of critical area in the mines were taken in every case, and all apparent damage to the mine workings and facilities caused by the event were also photographed.

Postdetonation examinations conducted to date have revealed damage in only two mines, the Cameo and Red Canyon Coal Mines at 27 and 32 miles, respectively, from the SGZ. The small but significant damage at Cameo can be definitely attributed to the Rulison event while the relatively minor damage at Red Canyon may or may not be. No observable damage was found in any of the other mines examined by the operators of the fringe area mines subsequently contacted.

AIR FORCE PARTICIPATION IN RULISON PROJECT

Air support for this test was arranged by the Continental Test Division, Directorate of Nuclear Field Operations, Headquarters Air Force Special Weapons Center (AFSWC), Kirtland Air Force Base, New Mexico. USAF support consisted of two UH-IF helicopters whose requirements were levied on the AFSWC by test command/defense Atomic Support Agency. Both helicopters were in place by D-5 days.

The helicopter missions originally required were security sweeps, documentary photography, and special flights as requested by the Director of Nuclear Operations.

Due to the remote location of the detonation site, the AFSWC detachment operated from two locations. The commander and operational/support functions, including aircraft staging, operated from the FAA Classroom at Walker Field, Grand Junction, Colorado. This classroom was an adequate headquarters. The second location was a helicopter pad established about 6 miles north of surface ground zero.

On D-day, all personnel were moved from Walker Field to the helicopter pad.

An Air Operations Center (AOC) was established in the Operations Coordination Center trailer in the Control Point complex about 2.5 miles north of SGZ. The AOC used a very-high frequency radio and an ultra-high-frequency radio.

On D-day, both helicopters departed Grand Junction at 0830 hours and began the required security sweeps. At 0920 hours, 22 hunters were found in a known deer hunters camp located about 2.5 miles southeast of SGZ. Heavy trains and a mired vehicle blocked the camps pre-planned evacuation route. By 1035 hours, a total of 22 hunters and 4 dogs had been evacuated to the town of Collbran, Colorado about 10 miles south of SGZ. Security sweeps were then resumed.

At 1425 hours, several smoke bombs were sighted approximately 020°/2 miles northeast of SGZ and 5 persons were sighted in the area by aircraft #7965. Aircraft #7957 picked up the Federal Marshal and one sheriff and proceeded to the area for removal of the protesters but when it arrived at 1435 hours, only 2 protesters could be located, and it was not until 1455 hours that they boarded the helicopter for takeoff. Both aircraft were airborne during detonation time at 1500 hours. After the law enforcement officers and the protestors were off-loaded, the 22 hunters and 4 dogs were transported back to their camp. Both aircraft returned to Walker Field at 1730 hours. All personnel and equipment had departed Grand Junction by 0600 hours on D+2.